DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150618

SOLAR HEATING AND COOLING SYSTEMS DESIGN AND DEVELOPMENT (Quarterly Report)

Prepared by

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George C. Marshall Space Flight Center, Alabama 35812

For the U. S. Department of Energy

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U.S. Department of Energy

Solar Energy

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SECTION I
SUMMARY

The Solar Heating and Cooling Development Program has a negative schedule variance and no cost variance through the first quarter, ending 30 September 1976.

The schedule variance is a result of an unplanned delay in initiating the Heating and Cooling Systems Design and Development tasks. Honeywell has delayed initiating Heating/Cooling subsystem activity originally planned to begin in the second month for the following reasons:

- NASA-MSFC strongly urged that we review our market positions with respect to heat pumps. The program baseline did not include deliverable heat pump systems.
- The staggered preliminary design reviews (October 1976 - for heating and January 1977 - for heating and cooling) would allow delay of the initial design and analysis tasks for the heating and cooling portion of the program without jeopardizing the timely completion of the contract. This would limit program cost problems if it is determined desirable to redirect our efforts due to the heat pump system mentioned above.

There are no projected cost or schedule problems predicted at this time due to the above schedule variance. However, delay by MSFC in providing specific site data could delay delivery of heating systems hardware.

A cost replan in the immediate future will take into consideration the current variance in the forward plan and any program changes resulting from the heating systems preliminary design review.

SECTION II

COST

This section has been deleted

SECTION III
SCHEDULES

Figures 9 and 10 show the progress to date in the heating and heating and cooling portions of the program.

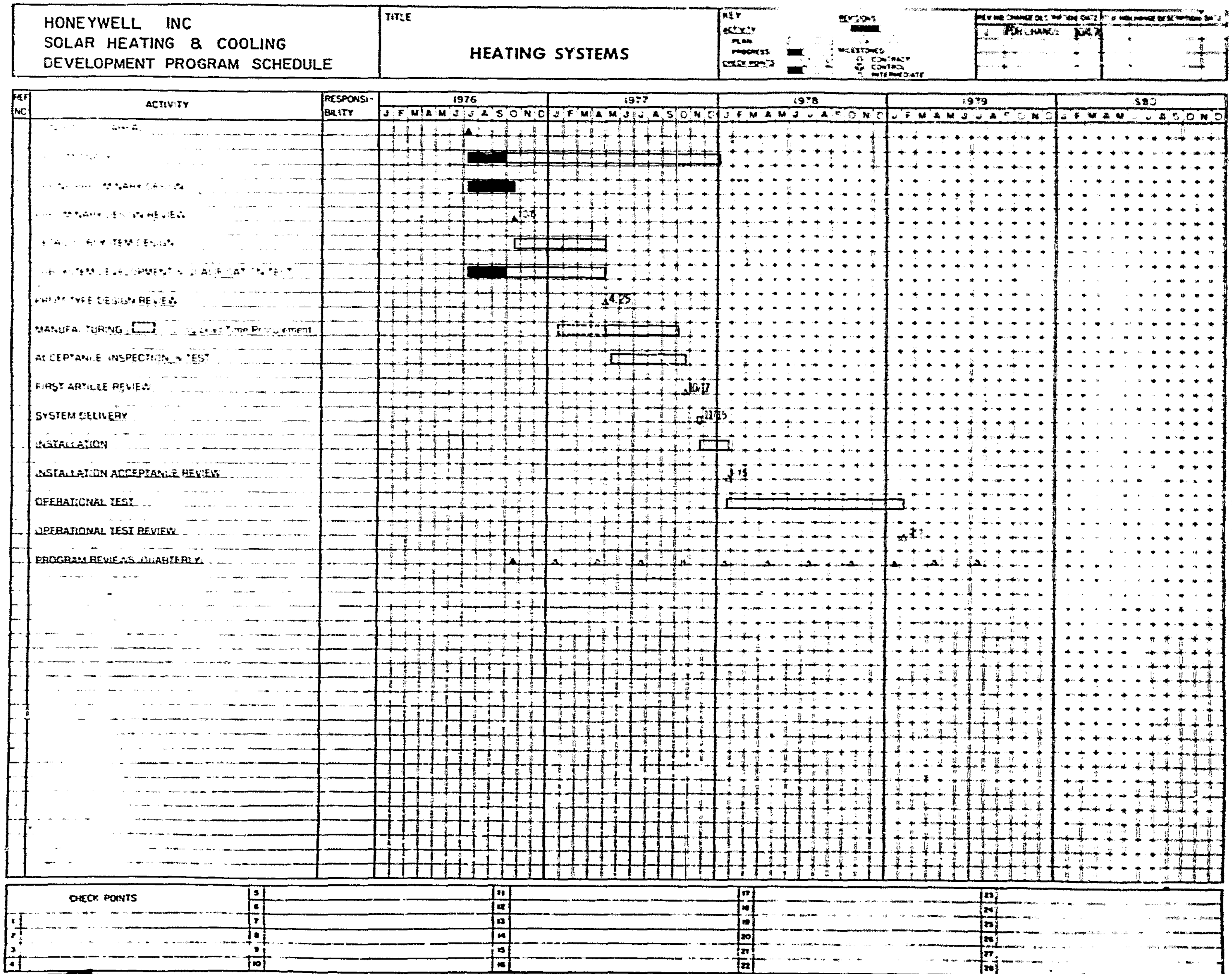


Figure 9. Heating System Development Program Schedule

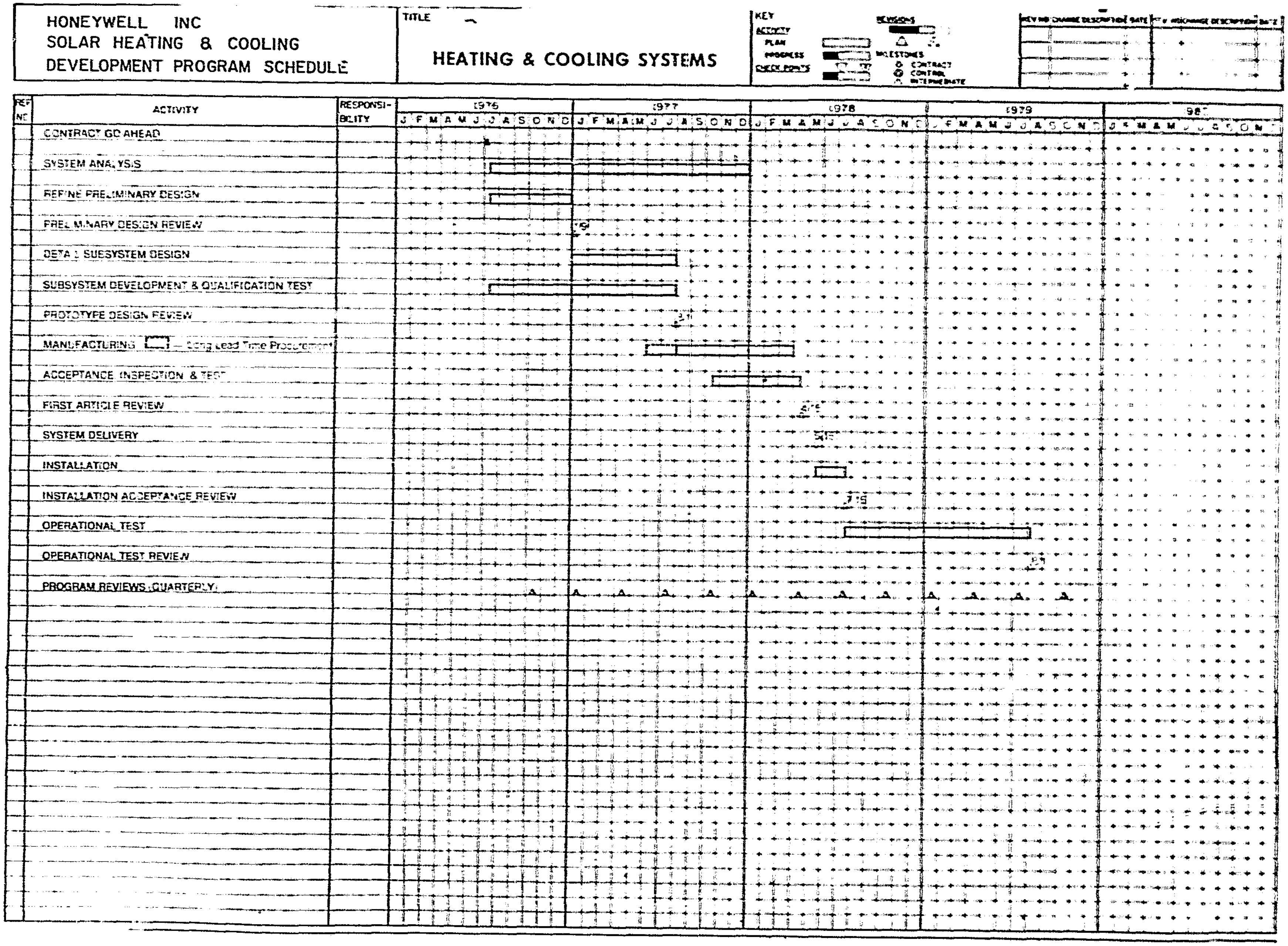


Figure 10. Heating and Cooling Systems Development Program Schedule

SECTION IV
TECHNICAL DISCUSSION

This section describes technical activities during the first quarter of the program.

APPROACH TO THE SELECTION OF DELIVERABLE SYSTEMS

Honeywell's approach to the selection of solar-heating systems is illustrated in Figure 11. Primarily, the approach consists of two parallel efforts: identification of all candidate solar-heating subsystem components, and identification of subsystem constraints or evaluation criteria. The next step, preliminary subsystem selection, is designed to narrow the list of candidate subsystem components, using the defined constraints. It becomes evident that the major components for system selection are collector type, storage medium, and auxiliary heating method.

The next step in system selection incorporates subsystem trade-offs and economic trade-offs to further reduce the number of workable and economically desirable systems. The subsystems upon which trade-offs are examined are the following:

- Collector
- Storage
- Auxiliary energy
- Working fluids
- Supplementary elements such as controls, piping, pumps, etc.

The economic analysis is made using methods which incorporate life cycle costing techniques to establish the most economical solar system.

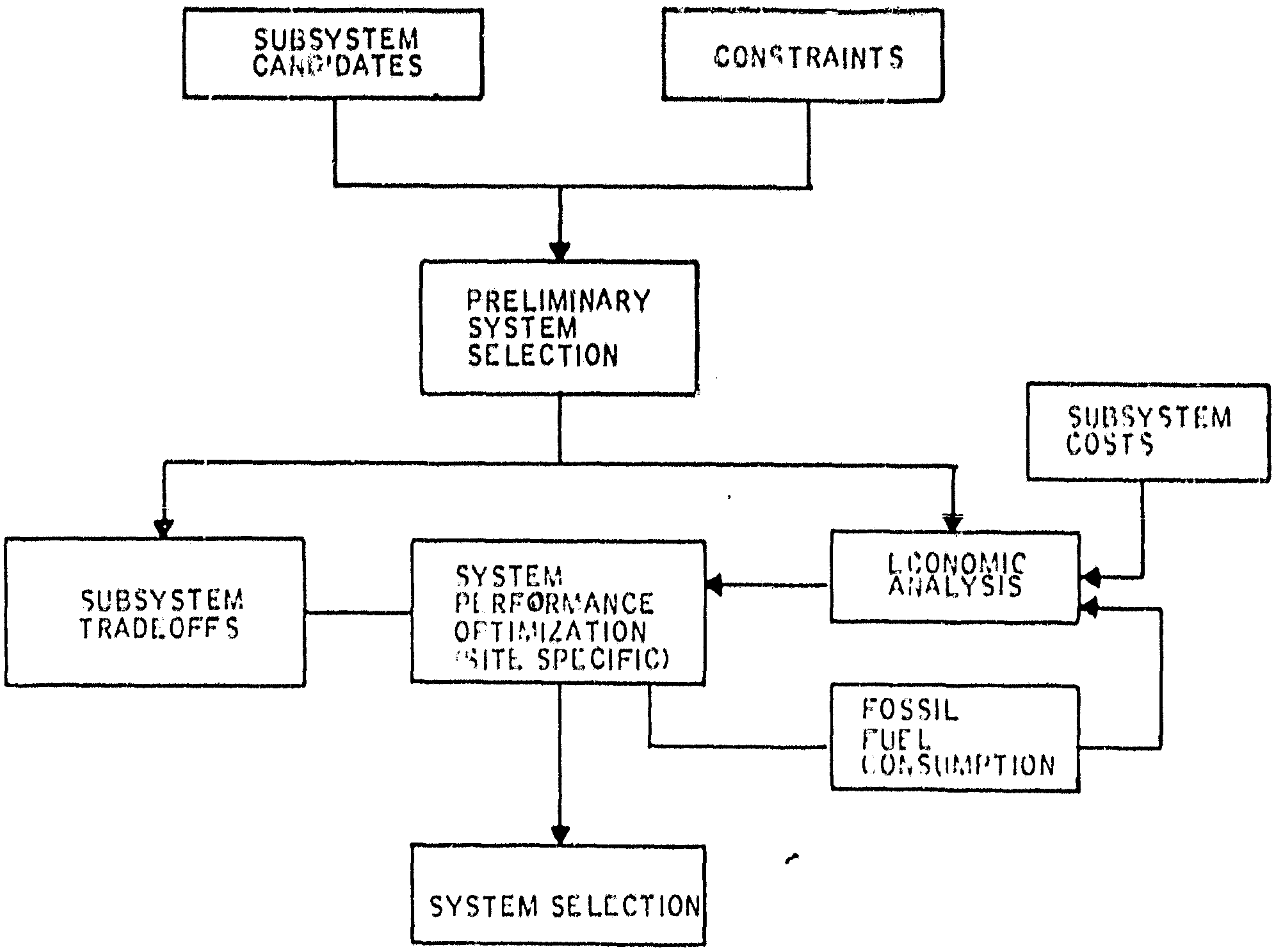


Figure 11. System Selection Flow Chart

The solar system performance is determined using Honeywell's Solar Systems Simulation Program. The economic analysis technique is used in conjunction with the simulation program to optimize the selected systems for the designated area and application.

SUBSYSTEM CANDIDATES

Subsystem candidates include all those solar heating system components that could be used to design heating systems. Candidate subsystem components identified are listed in Table 2. The table includes all those subsystem components that appear to be feasible candidates. Subsystem candidates are categorized by collectors, storage, auxiliary subsystems, working fluids, and supplementary elements.

CONSTRAINTS AND DESIGN CRITERIA

Constraints or evaluation criteria have been identified for purposes of performing preliminary and detailed trade-offs of subsystem components. These include:

- Modularity -- subsystems components that are of standard design and size that can be put together to achieve the desired capability. An example that meets this constraint is the flat plate collector panel, a component of standard size that can be combined to create any desired collector area.
- Scalability -- a subsystem component of standard design that can provide a progressive increase in capability by changing some of the components of that subsystem. An example of this type of subsystem component is the standard home furnace, the output capability of which can be increased by scaling burners and blower motor.

Table 2. Subsystem Component Candidates

Subsystem	Component
Collectors	• Liquid flat plate • Concentrator: - Tracking - two planes - Partial tracking - tracking in one plane - Nontracking - fixed • Air heater
Thermal Storage Media	• Water • Ethylene glycol/water solution • Rock pile • Heat-of-fusion materials
Auxiliary Subsystems	• Fossil fueled forced air furnace • Fossil fueled hydronic boiler • Heating only heat pumps
Working Fluids	• Air • Water/ethylene glycol • Water • Oil • Heat transfer fluids
Supplementary Elements	• Fans • Ducts • Controls • Piping • Pumps

- Architectural Aspects -- includes interface of solar heating systems on a building (especially collectors), impact on construction and aesthetic qualities
- Fuel Type Availability -- assurance that local utilities will provide the type and amounts of fuel required
- Economic Aspects -- costs of procurement, installation, maintenance and operation
- Development Risks -- availability of components within required time frame - subsystem design maturity
- Maintainability -- skill, knowledge and training required to maintain system
- Reliability -- confidence in assuring continued system operation over life cycle
- Safety -- safety of operation and use of system
- Control Philosophy -- control of solar heating system to use needed energy directly from collector or storage. Store excess energy and use auxiliary energy when required.

PRELIMINARY SUBSYSTEM COMPONENT SELECTION

The preliminary subsystem selection is designed to narrow the list of subsystem candidates for final consideration. By using the constraints identified, advantages and disadvantages of each subsystem component are examined with respect to these constraints. Relative strengths and weaknesses are identified and components can be ranked with respect to each other.

It becomes evident that collectors, auxiliary heating, and storage subsystems are the three most critical elements of heating system designs. Other subsystems, such as space heat, domestic hot water and controls, are easily defined after the selection of these three primary subsystems. There are three types of collectors which have been considered, liquid cooled flat plate, concentrators and air heaters. The types of auxiliary heating subsystems are a fossil fueled or electric forced air furnace, a fossil fueled or electric hydronic boilder and the third is an electric heat pump. Storage choices are rock, water and salt. The matrix shown in Figure 12 defines various system possibilities.

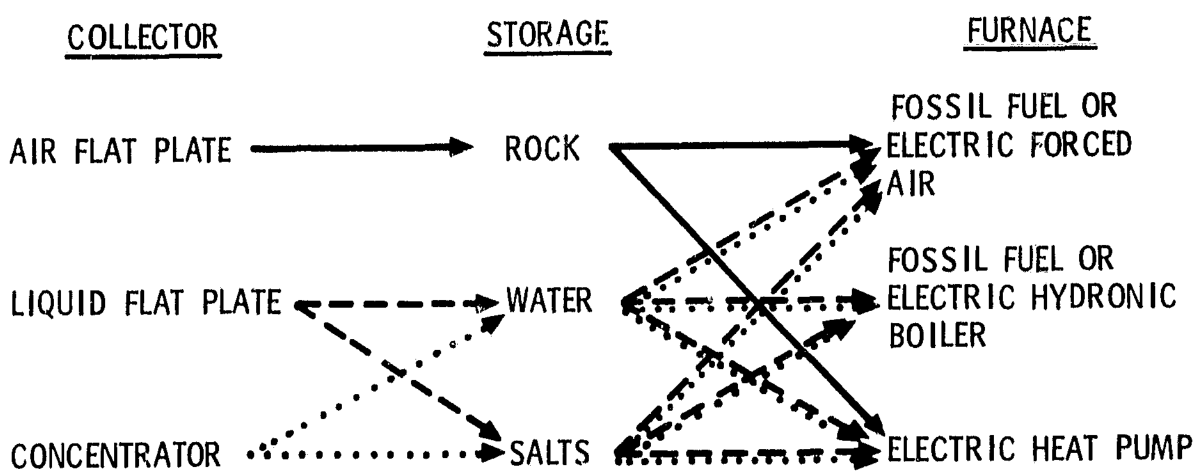


Figure 12. Possible System Combinations

Some system combinations were eliminated because of the general mismatch between subsystems such as air collectors and water storage. Some combinations may be possible but development risks at present outweigh advantages (i.e., air collectors with salt storage). Other general trade-offs are listed below for each of the three major subsystem types.

Collector type --

- Air and liquid flat plate collectors are generally simpler and offer less development risk than concentrator collectors.
- Liquid flat plates are slightly better than air collectors based on performance and development risk criteria.

Storage type --

- Phase change storage systems require a significant development risk.
- Liquid storage is more efficient than rock storage and is readily available from storage tank manufacturers.

Auxiliary subsystem type --

- Fossil fuel or electric forced air furnaces are the most common heating source and are easily adapted auxiliary energy subsystems for solar system applications.
- Heat pumps for solar application require development and some initial system cost increases.
- Due to the potential shortage of gas and oil in various regions, heat pumps may be necessary as auxiliary heating units.

The system providing the best match of subsystem components with the smallest development risk for space heating applications is a liquid cooled flat plate collector with sensible heat water storage and a gas fired forced air furnace as the auxiliary heating source. In the event that gas is not available, heat pumps or electric furnaces may be considered in conjunction with the solar heating system.

Numerous other workable systems exist for heating applications. Further studies and trade-offs could yield insights into the use of concentrators or air heaters along with the associated storage and auxiliary energy subsystems mentioned above for space heating applications.

BASELINE SYSTEMS

The proposed solar assisted heating systems are two fluid loop solar collector systems interfacing with conventional fossil fuel fired furnaces. These proposed system designs may be easily sized to fit a wide spectrum of applications. First, the collectors are modular and can be combined in arrays to satisfy site-specific collector configurations. Second, the auxiliary subsystems are selected from a broad product line of fossil fuel-fired warm air furnaces, allowing many choices to fit site-specific requirements. Finally, the storage, hot water, transport and control subsystems are commercially produced items in a broad range of sizes. This subsystem modularity allows variations in system design to accommodate the variable performance requirements that are expected nationwide.

The proposed solar systems are designed to maximize the amount of solar energy collected for use and storage. This is accomplished by:

- A control system that minimizes collector inlet temperatures (maximizes energy into the building)
- Optimum transfer rate heat exchangers
- Direct collector to space heating by by-passing storage.
- Using high-performance flat plate collectors

- Storage which can be operated in parallel and independently from collector loop

System reliability and maintainability is assured through design features which include the following:

- A closed collector loop for over temperature protection via a purge coil

- A control system employing simple logic

- A minimum of components in the system

- Manifolding external to the collector modules .

Maintenance of space temperature, hence occupant comfort, is assured through the use of the following components and design techniques:

- A two-stage thermostat with a min imum differential for solar operation

- Conventional furnace control of air temperature to the space

The systems have been designed to minimize contamination of the potable water supply by the use of:

- A two-fluid loop system that isolates the collector heat transfer fluid
- A system in which domestic water pressure is higher than system pressures

Single Family Residential Heating System Description

The proposed system for a single family residential heating system is a two-fluid-loop, solar assisted, hydronic-to-warm-air system with solar assisted domestic water heating. The system is composed of the following major components:

- Liquid cooled flat plate collectors
- A water storage tank
- A passive solar fired domestic water preheater
- A gas fired hot water heater
- A gas fired warm air furnace with hot water coil unit
- A tube-and-shell heat exchanger, three pumps and associated pipes and valving
- A control system
- An air-cooled heat purge unit

A schematic of the system configuration is shown in Figure 13. The solar collectors supply heat to the furnace through the hot water coil in the furnace return air section and to the storage both through the tube-and-shell heat exchanger in the collector loop. Heat is withdrawn from storage to the hot water coil in the furnace when energy from the collectors is not available. Domestic hot water heating is supplied from storage by the passive heating system in the storage tank. Auxiliary heat is supplied by the gas fired section of the warm air furnace and domestic water heating is tempered by the gas fired hot water heater. The system operates on a priority load basis, providing energy to the space heating load whenever the solar collectors have adequate energy available and the load demands heat. If the space heating load is not demanding energy, the solar collectors can provide energy to the storage tank and hence to the domestic hot water preheater. The storage tank can supply energy to the space heating load and to the domestic hot water system if the solar

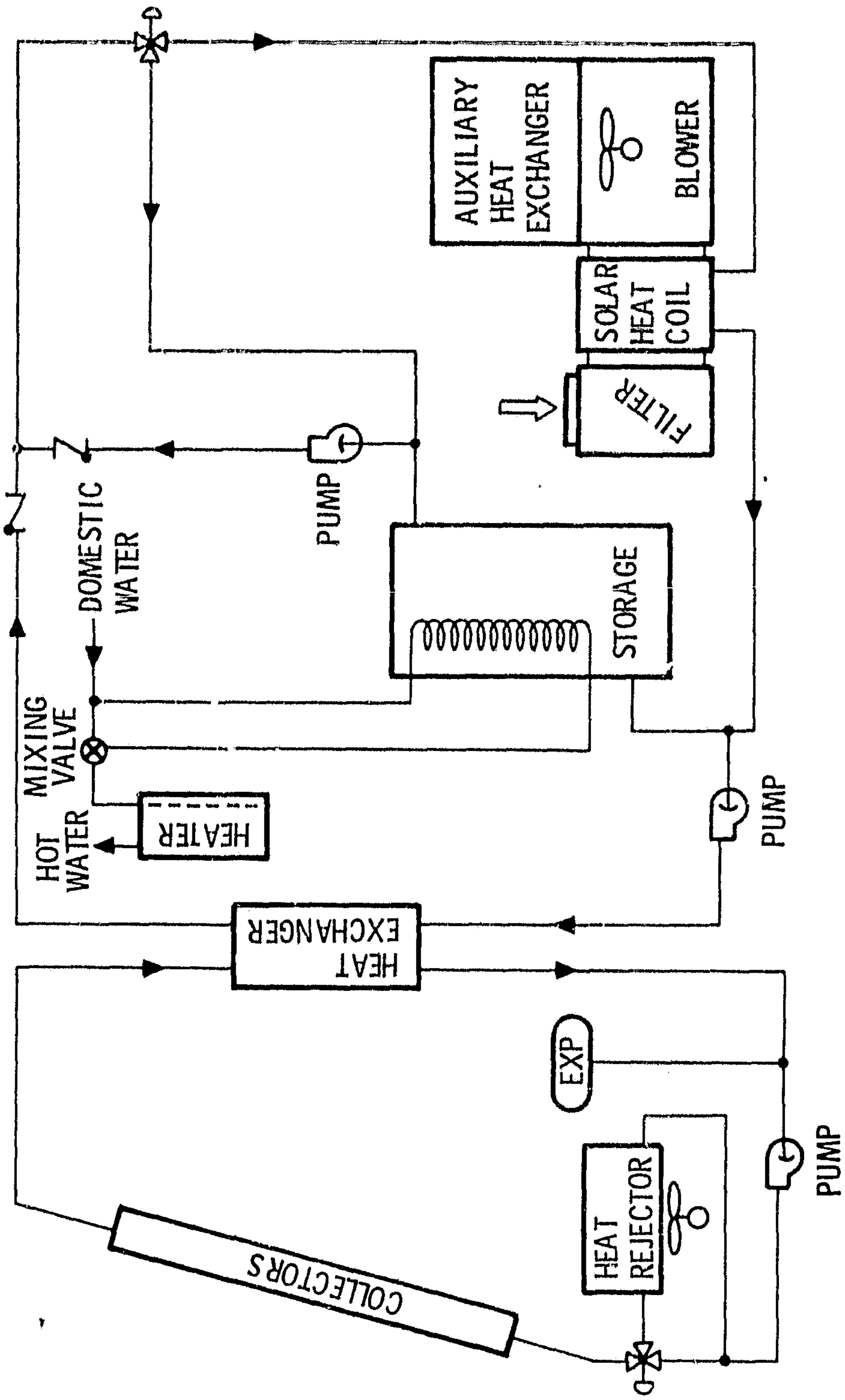


Figure 13. Residential Heating System Schematic

collectors do not have adequate energy available. In the case of high solar availability and no energy demand from space heating, domestic hot water, or storage load, a purge coil has been provided to dissipate the excess energy.

Multifamily Residential Heating System Description

The proposed system for a multifamily residential dwelling is a two-fluid-loop primary-secondary circulation system for hydronic-to-warm-air heating with solar assisted domestic water heating. The system will provide heat for 12 apartments through individual gas fired furnaces with hot water coils in the return air system, and domestic water to the apartments through a central domestic water heating system. The system has the following major components:

- Liquid cooled flat plate collectors
- A water storage tank for sensible heat storage
- An active solar fired domestic water preheater
- Three gas fired water heaters
- Twelve gas fired warm air furnaces with hot water coil unit
- A tube-and-shell heat exchanger, two main circulating pumps, 12 secondary pumps, 1 hot water pump and associated pipes and valving
- Control system
- An air-cooled heat purge unit

A schematic of the system configuration is shown in Figure 14.
The solar collectors supply heat to the apartment units through the hot water coils in each furnace. The gas fired domestic water heaters are connected in parallel to provide the capacity requirements of the RFP.

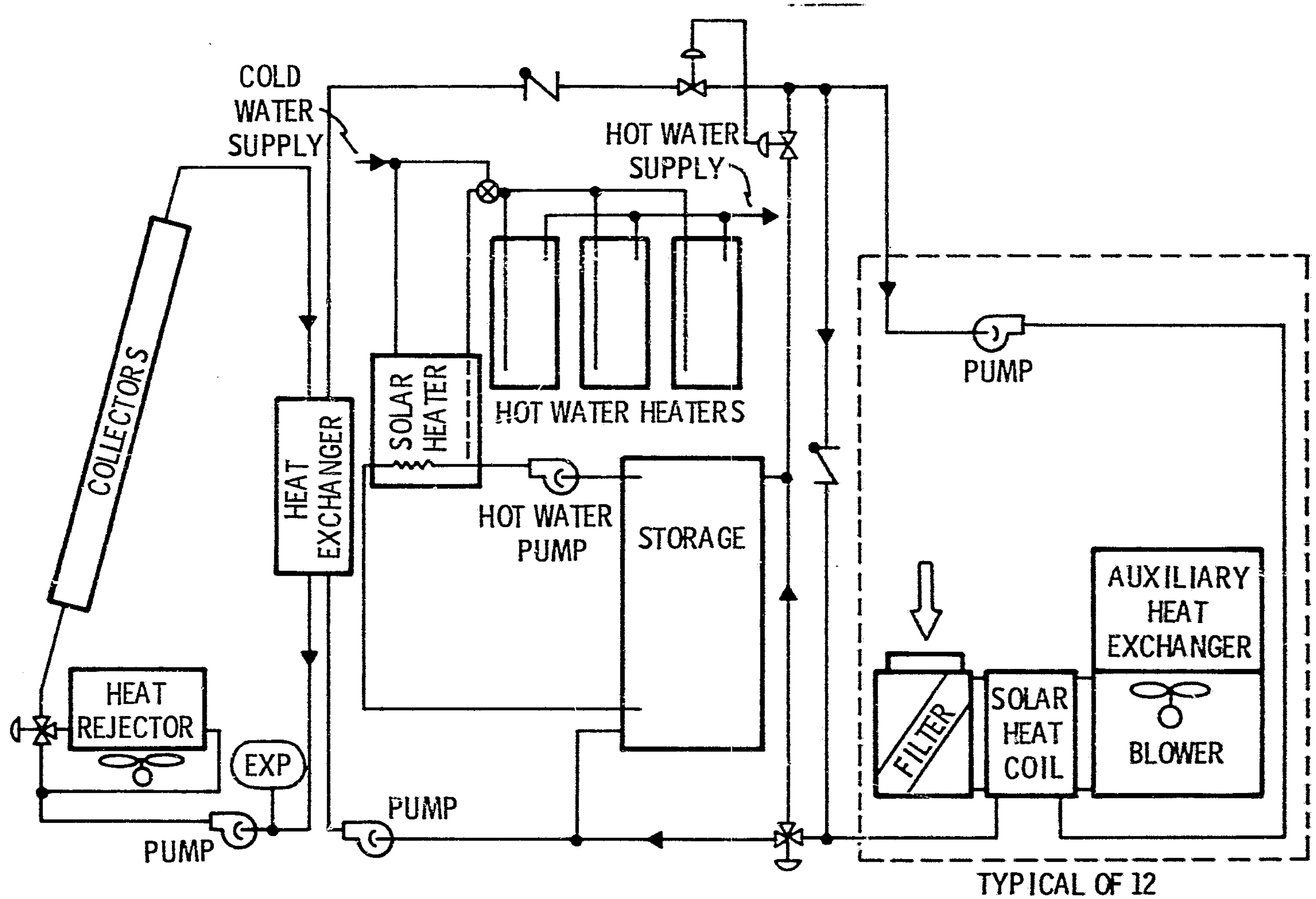


Figure 14. Multifamily Heating System Schematic

The system is similar to the single family residence heating system only in that both have pressurized collector loops isolated from the non-pressurized water loop through a tube-and-shell heat exchanger. In addition, the multifamily residence system has a series of secondary pumping loops to each multifamily unit. These secondary loops provide for independent supply of solar heated water without the expenditure of excessive pumping power requirements. The control system is an expanded version of the single family system.

Commercial Applications Heating System Description

The proposed system for commercial building heating is a two-fluid-loop, primary-secondary circulation system for hydronic-to-warm-air heating with solar assisted domestic water heating. The system will provide space heating through gas fired rooftop heating furnaces, and domestic water heating through a solar heated preheater and gas fired water heater. The system is composed of the following major components:

- Liquid cooled flat plate collectors
- A water storage tank for sensible heat storage
- An active solar fired domestic water preheater
- A gas fired water heater
- Gas fired, rooftop mounted furnaces with hot water coil units
- A tube-and-shell heat exchanger, two main pumps and four secondary pumps and associated pipes and valves
- A control system
- An air cooled heat purge unit

A schematic of the proposed system configuration is shown in Figure 15. The system is similar in operation to the residential and multifamily systems and will provide for four zones of heating with operation of each zone similar to the residential system or to the multifamily heating system.

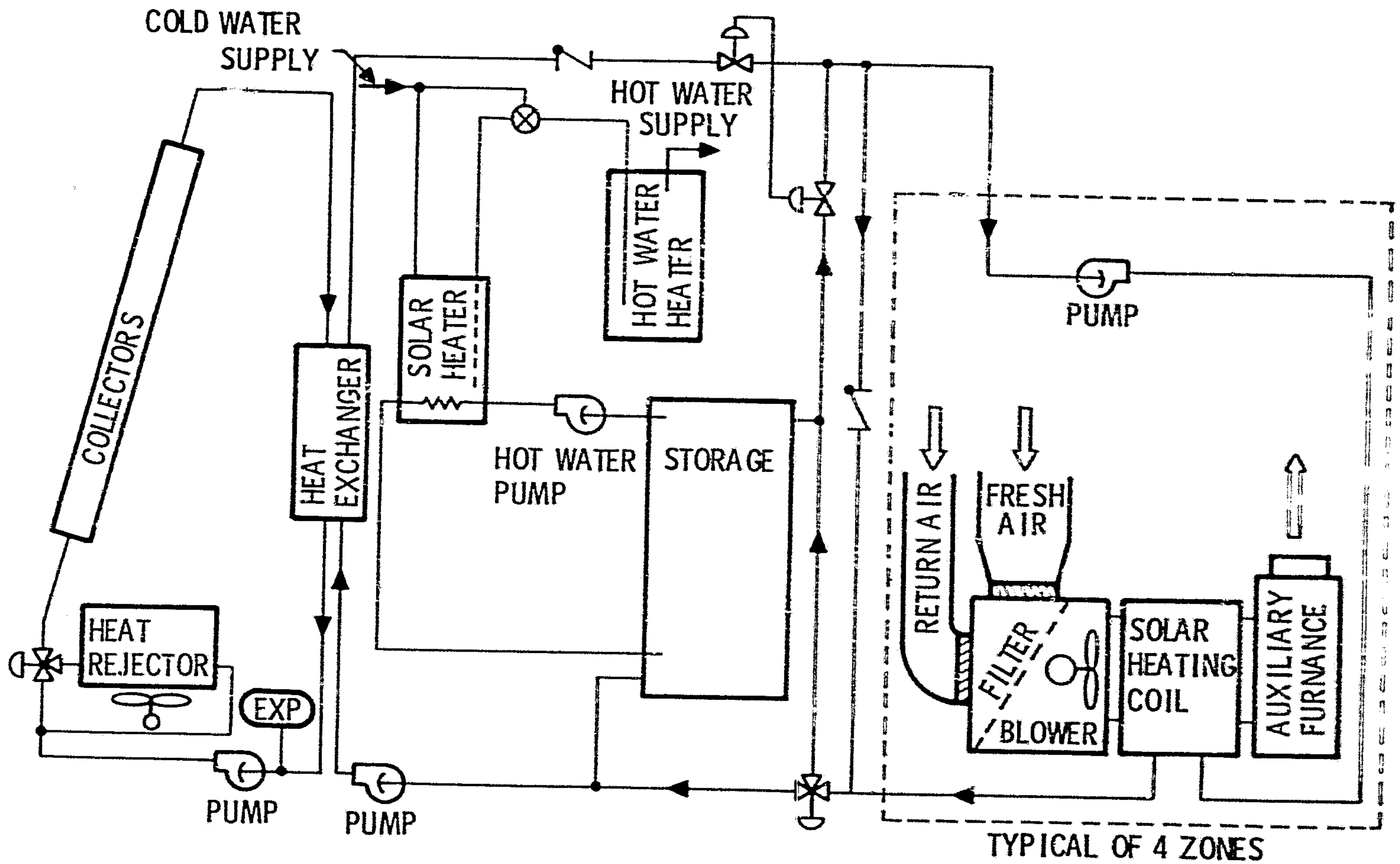


Figure 15. Commercial Building Heating Schematic

TRADE STUDIES

Methodology

A methodology for a comparison of solar-assisted heating system concepts has been established. The methodology or approach allows a complete examination of the solar system and subsystem candidates. In order to assure that the solar systems development results in products that meet the requirements, the studies included variations in key parameters that influence solar heating systems costs and performance. A systems simulation program was used to study the solar systems cost and/or performance variation as a result of a variation in the key parameters.

The system tradeoff methodology is shown schematically in Figure 16.

Criteria

The criteria for selection of a solar system configuration will be the following.

- Minimum annual cost per million Btu solar energy provided
- System safety
- Development risk
- Architectural considerations

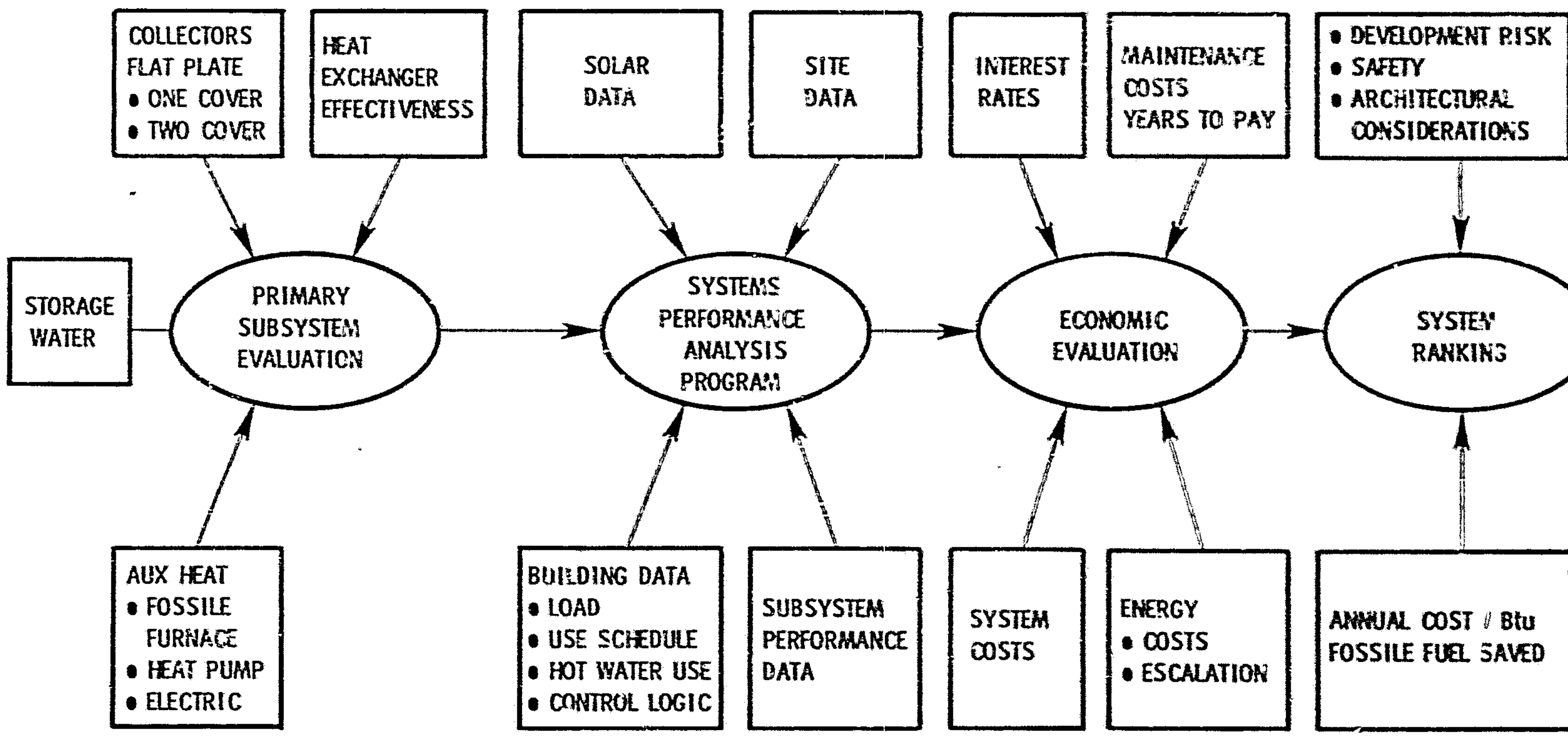


Figure 16. System Tradeoff Flow Chart

Parameters and Assumptions

The prediction of the performance and economics of a solar heating system is based on a simulation analysis using observed weather and solar data generated from cloud cover. The actual system is simulated by a digital computer code on an hour-by-hour basis.

Since specific government selected sites were not available prior to the heating systems preliminary design review, Minneapolis was selected as a site for the systems. A description of the basic parameters and assumptions used in the trade-off studies follows.

Site -- Minneapolis was selected as the site for the tradeoff studies for heating systems. Minneapolis is located at 44.7 degrees north latitude and 93 degrees longitude.

The mean daily total solar radiation for Minneapolis is approximately 345 Langleys. This value varies from about 125 Langleys in December to about 560 Langleys in June. The contoured charts of solar radiation are shown in Figures 17 and 18. These data were taken from the Climatic Atlas of the United States published in 1968 by National Climatic Center, Asheville, North Carolina. The national charts showing mean percentage of sunshine and total hours of sunshine are presented in Figures 19 and 20. An interpolation of these charts shows that Minneapolis has approximately 2550 hours of sunshine annually, or approximately 55 percent of the possible sunshine.

The average annual degree days for Minneapolis is 8382. (Reference ASHRAE Systems Handbook, Chapter 43.4). The average heating season temperature, October to April, is approximately 28 F. The monthly average degree days in shcwn in Table 3.

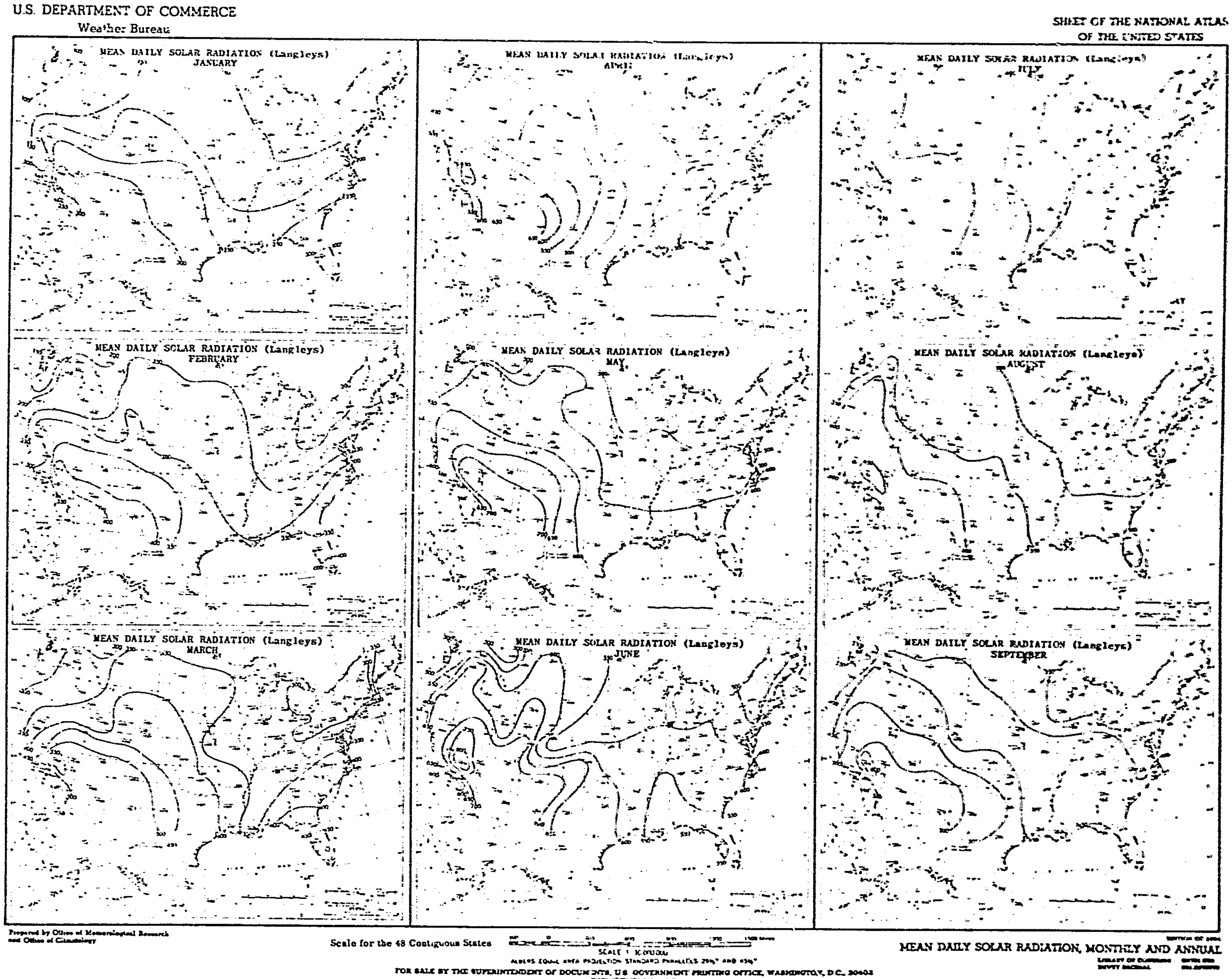
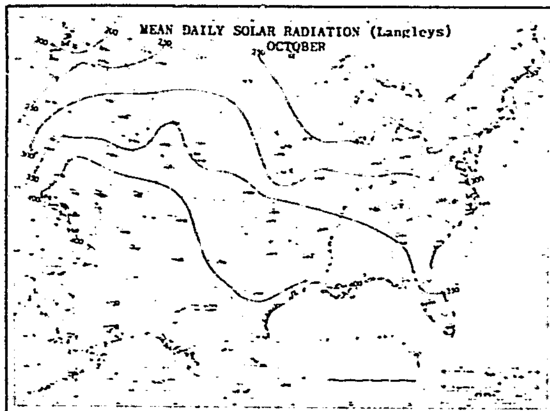
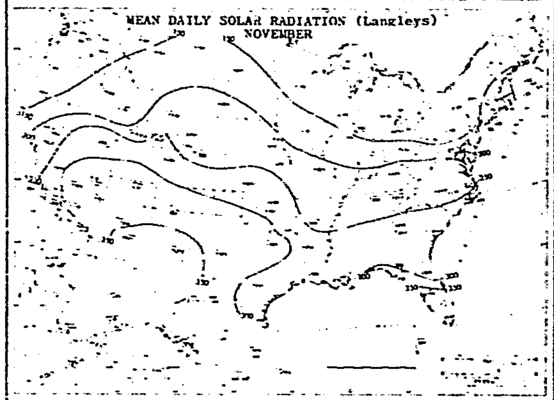
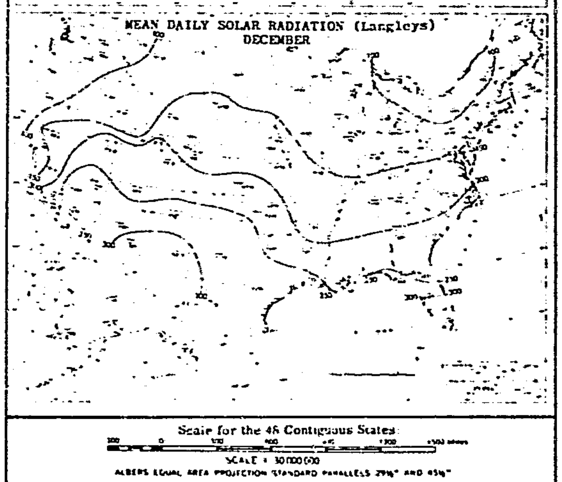
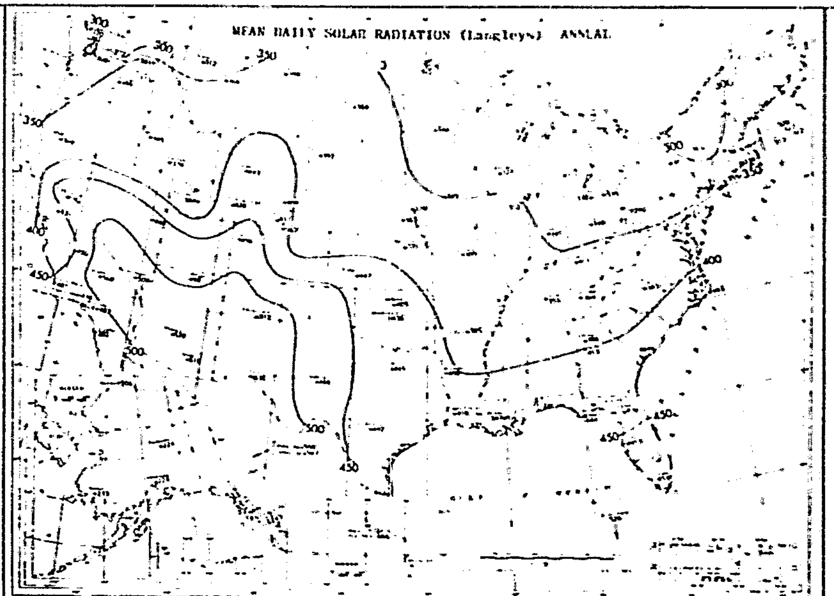


Figure 17. Mean Daily Solar Radiation, Monthly and Annual









These charts and table are based on all usable solar radiation data, direct and diffuse, measured on a horizontal surface and published in the Monthly Weather Review and Climatological Data National Summary through 1962. All data were measured in, or were reduced to, the International Scale of Pyrheliometry, 1956.

Langley is the unit used to denote one gram calorie per square centimeter (1 langley = 1 gm. cal. cm^{-2}).

MEAN DAILY SOLAR RADIATION (Langleys) AND YEARS OF RECORD USED

[illegible]

Figure 17. Mean Daily Solar Radiation, Monthly and Annual (Concluded)

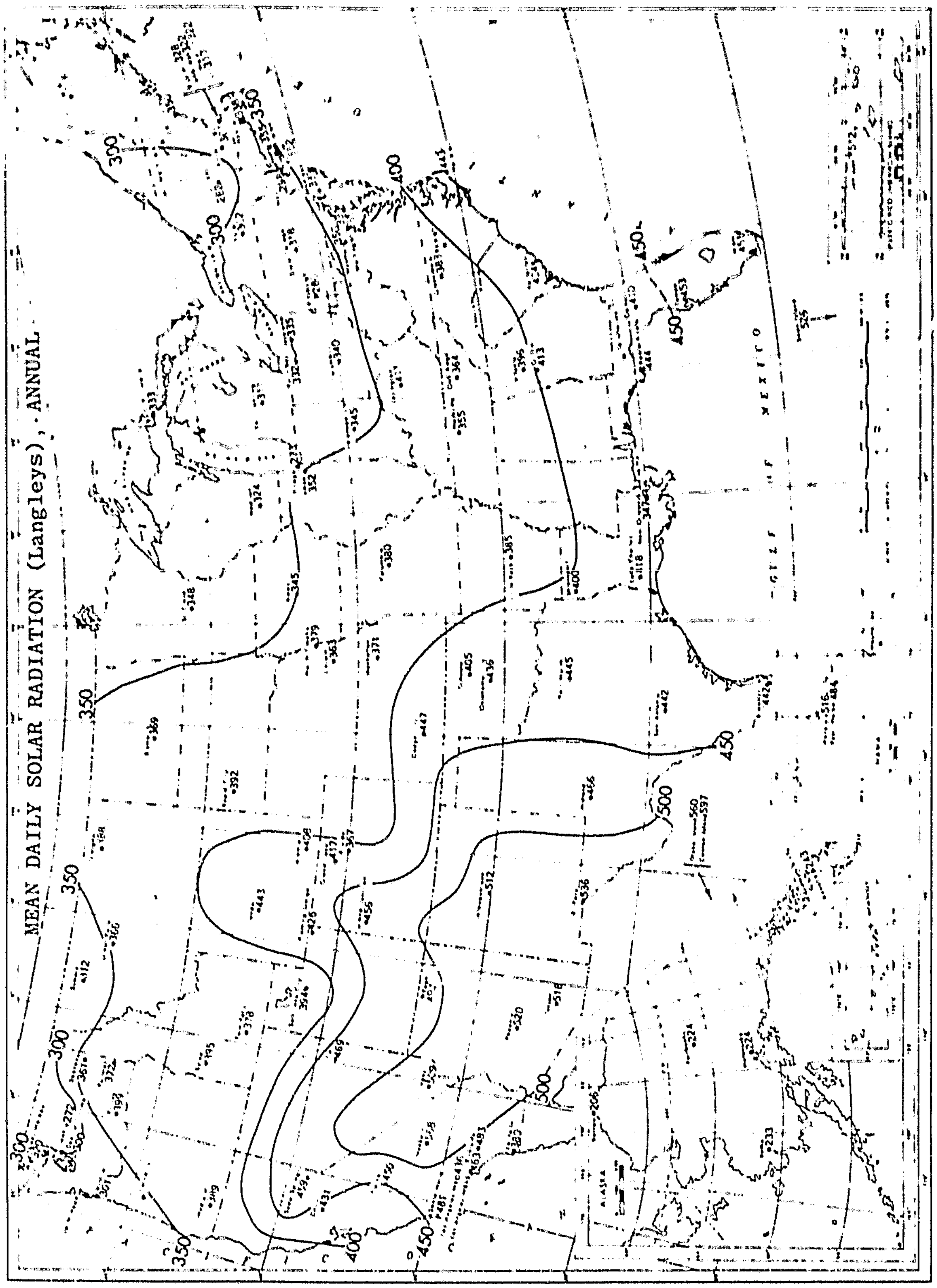


Figure 18. Mean Daily Total Radiation, Annual

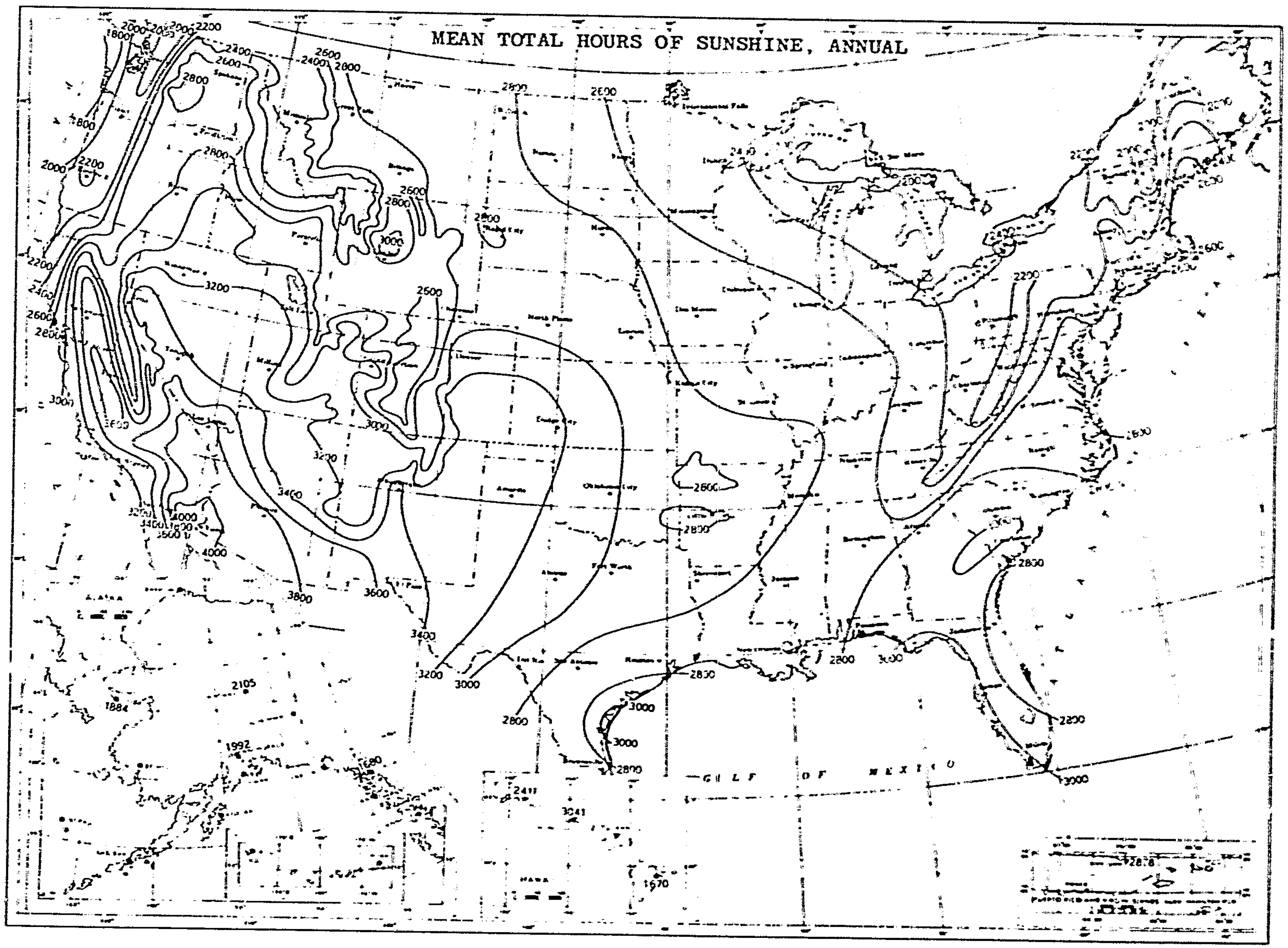


Figure 19. Mean Total Hours of Sunshine, Annual

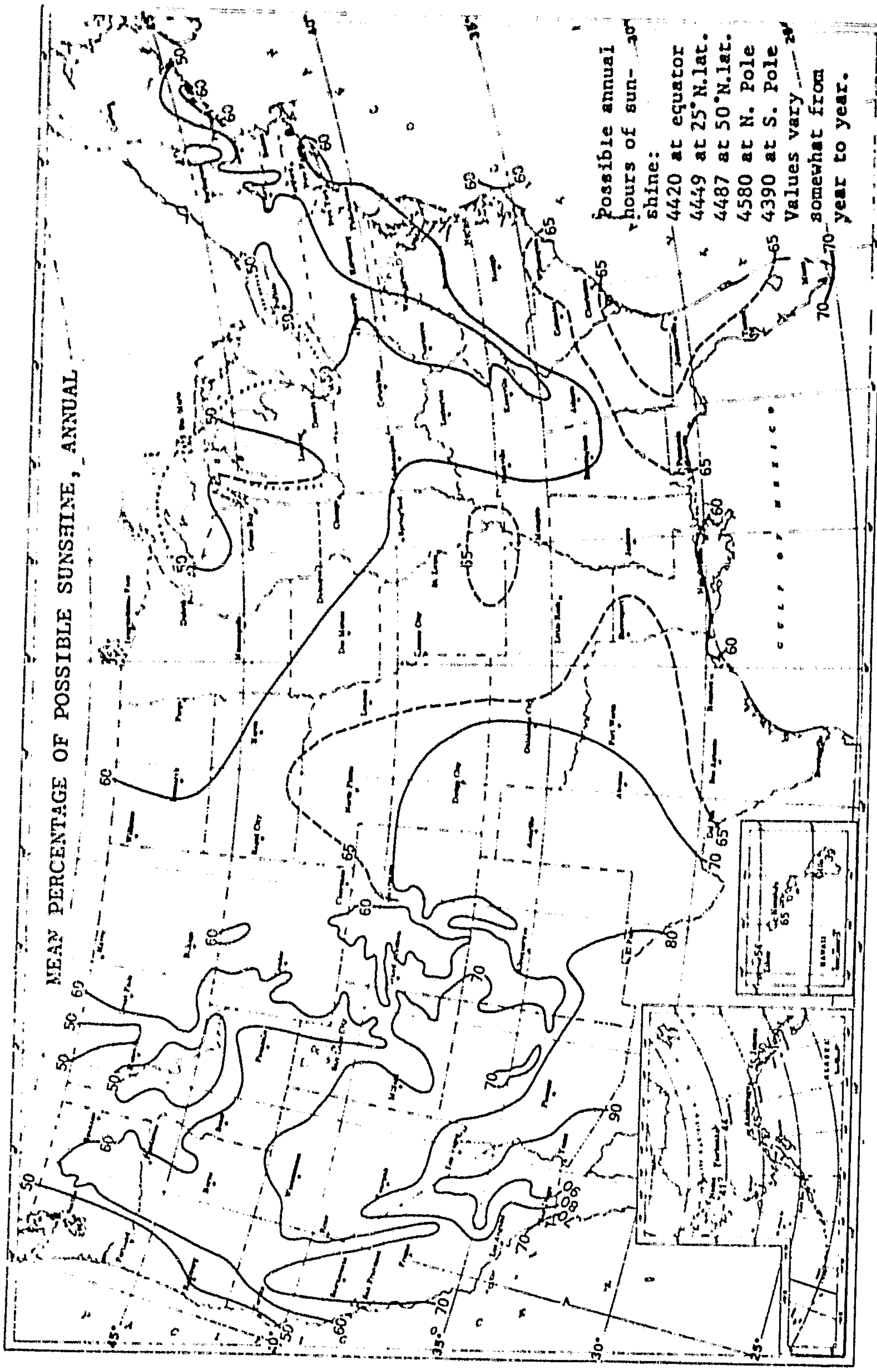


Figure 20. Mean Percentage of Sunshine, Annual

Table 3.

Average Monthly Degree Days for Minneapolis

January	1631
February	1380
March	1166
April	621
May	288
June	81
July	22
August	31
September	189
October	505
November	1014
December	1454
Total	8382

Heating System Design Conditions -- The heating system design conditions are based on the requirements outlined in Interim Performance Criteria for Solar Heating and Combined Heating and Cooling Systems and Dwellings (IPC).

Inside Design Conditions - Winter -- The heating plant capacity will be based on the maximum instantaneous block heat loss at outside winter design when calculated for an inside temperature of 70°F dry bulb, and the selected relative humidity for the project if applicable.

Outside Design Conditions -- The design will be based on weather data given in the latest issue of the applicable ASHRAE Guide. The heating load will be designed on the basis of the coincident wind velocity and the 97 1/2 percent column. These conditions for Minneapolis are:

Winter: -10°F (97 1/2% column)

For reference, the medium of annual extremes for Minneapolis is -19°F.

Building Heating Loads -- The building heating loads are based on the ASHRAE standard 90-75. Since no specific buildings or sites have been identified, typical sizes have been used for calculating the energy demands for heating a single family and multifamily residence and a small commercial building.

Single Family Residence -- The single family residence was assumed to be a single story, 1500 ft^2, rectangular building (25 x 60 ft), facing south. The "U" values for the walls and ceiling were taken from ASHRAE standard 90-75. For Minneapolis with 8382 degree days, Figure 21 shows for a type "A" building, the "U" value is 0.185 Btu/hr - ft^2°F. (Reference ASHRAE 90-75 paragraph 4.3.2.2.)

The overall thermal transmission conductance is the combination of heat flow through the walls and ceiling.

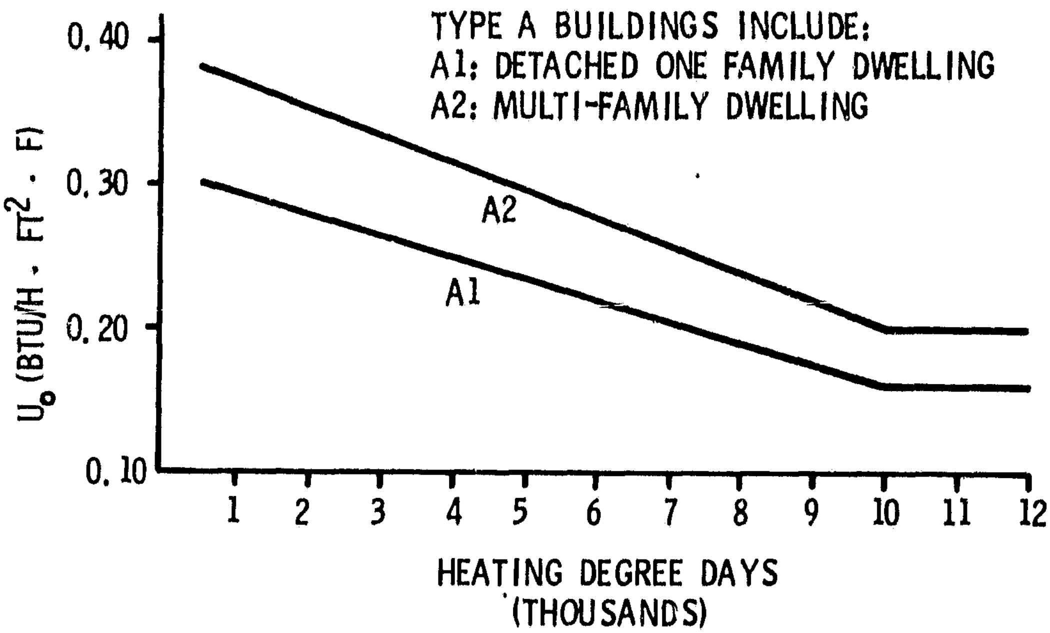


Figure 21. U_o Walls - Type "A" Buildings

$U_{WALL} = 0.185$

$U_{CEILING} = 0.04$

$UA_{TOT} = 0.185\ (170)\ (8) + 1500\ (0.04) = 311.6\ Btu/hr\,^{\circ}F$

This value includes the transmission through any doors and windows included in the outside walls.

The infiltration through cracks and seams was assumed to be .75 air changes per hour. For a 1500 ft^2 house with an 8 ft. ceiling this is 9000 ft^3/hr of outside air which has to be heated.

$$\text{For infiltration } UA = \dot{m}C_p = 9000\ (.24)\ (.075)$$
$$= 162\ Btu/hr\ F$$

The total "UA" including transmission and infiltration is:

$$UA_{TOTAL} = 162 + 311 = 473\ Btu/hr\ F$$

The design load for the single family residence is:

$$Q = UA\ (T_{ROOM} - T_{AMBIENT})$$

$$Q = 473\ (70 - (-10)) = 37840\ Btu/hr$$

Our internal load was assumed to account for people and lights. This load schedule was:

8 a.m. - 8 p.m.	--	2550 Btu/hr
8 p.m. - 8 a.m.	--	1350 Btu/hr

<u>Multifamily Residence</u> -- The multifamily residence was assumed to be a 12 unit, two story, 15,000 ft^2, rectangular building (70 x 105 ft), facing south. Each unit would contain 1250 ft^2. The "US values for the walls and ceiling were taken from Figure 21 and paragraphs 4.3.2.2. of ASHRAE 90-75.

$$U_{WALL} = .23$$

$$U_{CEILING} = .04$$

The overall transmission is calculated as:

$$UA_{TOTAL} = .23\ (350) + .04\ (7350)$$
$$= 1582 \text{ Btu/hr F}$$

The infiltration, as with the single family residence, was assumed to be 0.75 changes per hours, or 90000 ft^3/hr.

$$UA_{INFILTRATION} = 90000\ (.075)\ (.29) = 1620 \text{ Btu/hr F}$$

$$UA_{TOTAL} = 1620 + 1582 = 3202 \text{ Btu/hr.}$$

An internal load schedule was assumed.

8 a.m. - 8 p.m. -- 25500 Btu/hr

8 p.m. - 8 a.m. -- 13500 Btu/hr

These internal loads are the same as was included in RFP-404.

Commercial Building -- The commercial building was a 32500 ft^2 single story, rectangular (100-325 ft^2)building. This is identical to the building size specified in RFP-404. The building loads are different from RFP-404 and were calculated from ASHRAE 90-75.

The "U" value for the commercial building was taken from Figure 22. For a building under three stories and 8382 degree days in Minneapolis, the "U" value is 0.23 Btu/Hr. ft^2F. The ceiling "U" value is 0.06 Btu/Hr. ft^2F as shown in Figure 23 for 8382 degree days. The combined transmission conductance is calculated for a 10 foot high wall as:

$$
\begin{aligned}
UA_{Transmission} &= .23\,(850)(10) + .06\,(32500) \\
&= 3905 \text{ Btu/Hr. F}
\end{aligned}
$$

The infiltration load was assumed to be the same as specified in RFP-404 as [illegible] cfm or $UA_{Infiltration}$ = 243 Btu/Hr. F

The ventilation schedule was also taken from RFP-404.

270000 ft^3/Hr. (UA=4860)	8 AM - 7 PM
0	7 PM - 8 AM

The internal load schedule for people and lights was:

Lights	213180 Btu/Hr.	8 AM - 7 PM
	106590 " "	7 PM - 8 AM
People	60000 " "	8 AM - 7 PM
	0 " "	7 PM - 8 AM

The total "UA" coefficient is:

$$
\begin{aligned}
UA_{Total} &= UA_{Trans} + UA_{Vent} + UA_{Infil} \\
&= 3905 + 243 + 4860 \\
&= 9008 \text{ Btu/Hr. F} \quad 8 \text{ AM} - 7 \text{ PM} \\
&= 4148 \text{ Btu/Hr. F} \quad 7 \text{ PM} - 8 \text{ AM}
\end{aligned}
$$

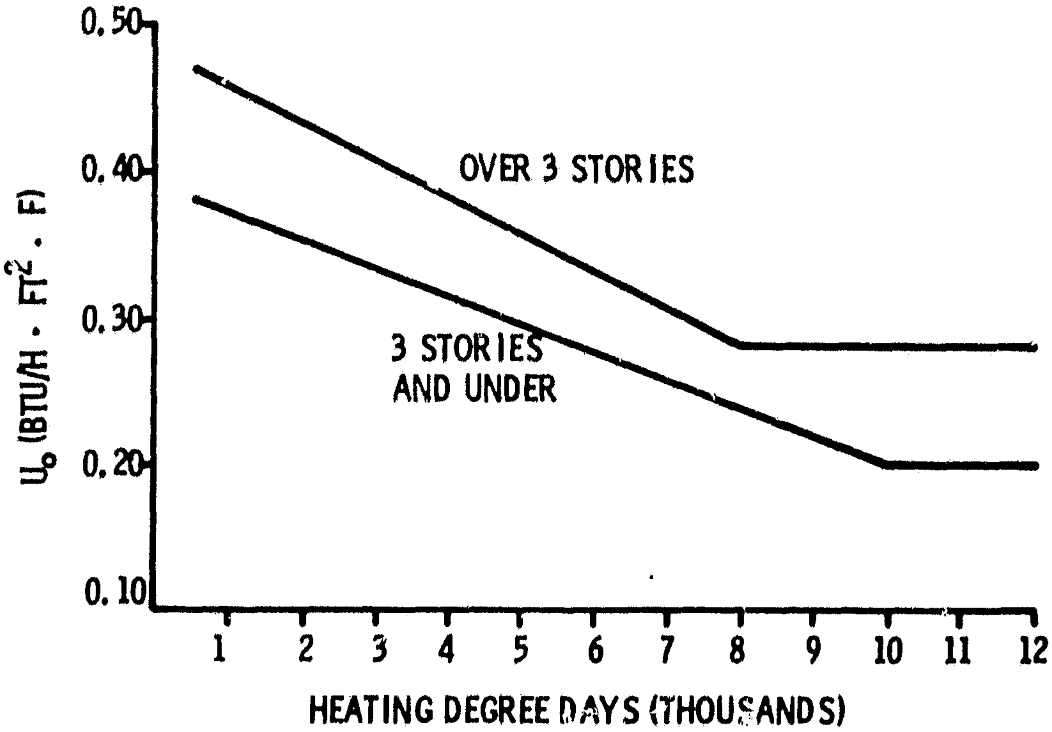


Figure 22. U_o Walls - Heating Type "B" Building

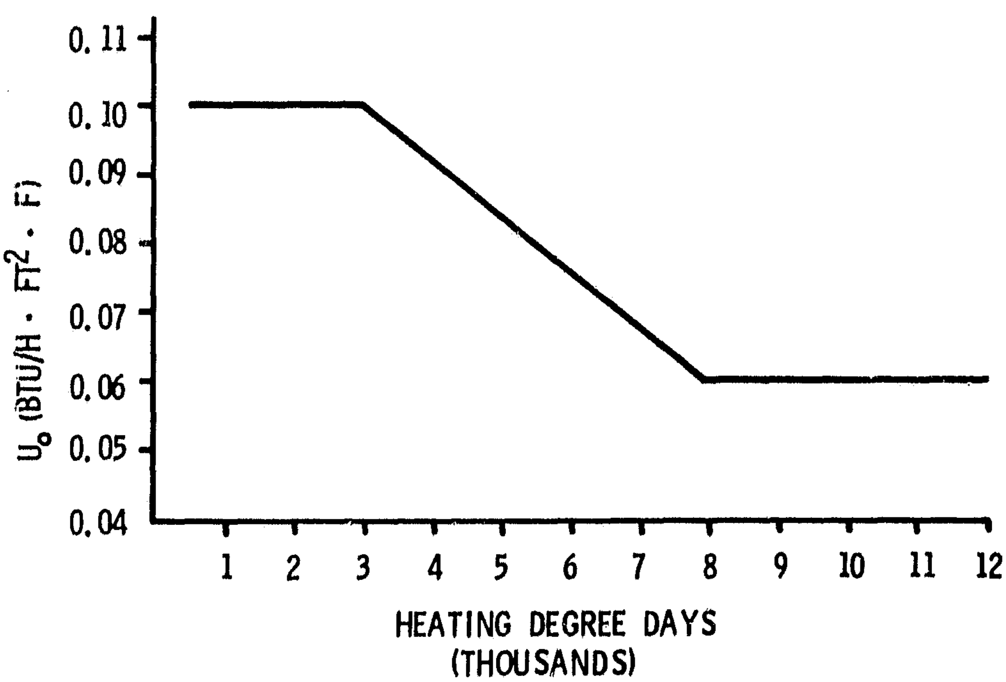


Figure 23. U_o -- Roofs and Ceilings Type "B" Buildings

Domestic Hot Water -- The domestic hot water schedule for the three types of building is shown below graphically in Figures 24, 25, and 26.

Time	Gal (SF)	Gal (MF)
7 am	50.4	630
10 am	9.8	122.4
1 pm	9.8	122.4
4 pm	9.8	122.4
10 pm	11.1	138.4
	100.7	1258.

Commercial building: 115 GPH 8 am - 7 pm
0 GPH 7 pm - 8 am

The energy requirements to heat the domestic hot water were calculated with the following assumptions (reference IPC).

delivery temperature = 140 F
supply temperature = well water temperature

The well water temperature for Minneapolis varies from 39 F to 57 F between summer and winter. (Reference NBSLD Computer Program for Heating and Cooling Loads in Buildings, NBS1R 74-574, T. Kusuda, November, 1974).

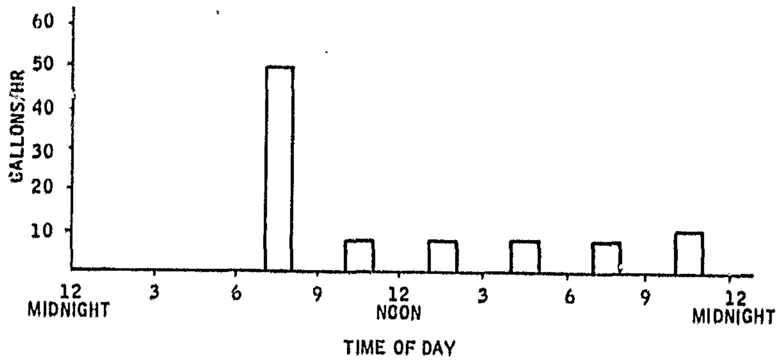


Figure 24. Assumed Use Profile for Domestic Hot Water - Single Family Residence

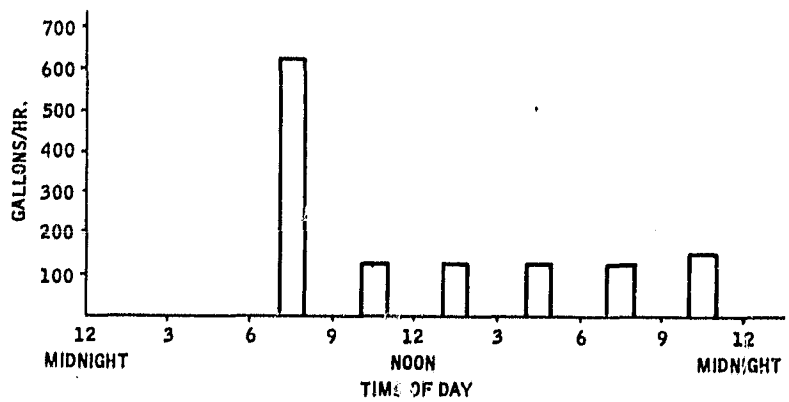


Figure 25. Assumed Use Profile for Domestic Hot Water - Multifamily Residence

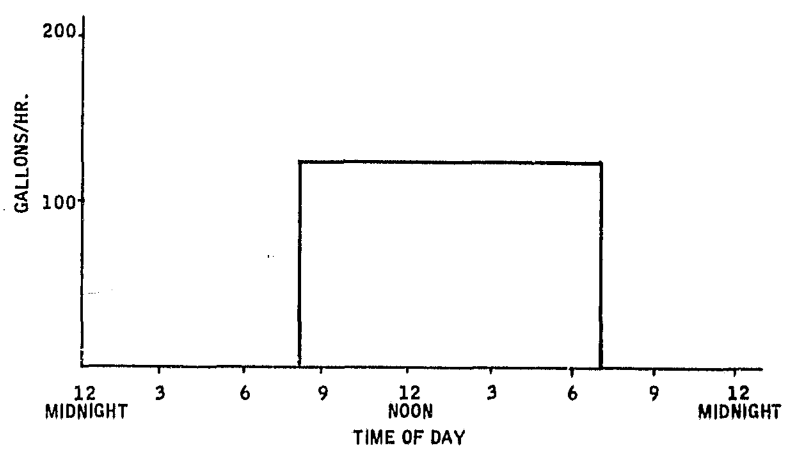


Figure 26. Assumed Use Profile for Domestic Hot Water - Commercial Building

Weather Model -- The following hourly recorded data is taken from weather tapes provided by the National Climatic Center, Asheville, N. C. (Reference Airways TDF-14, Surface Observations Manual, Director National Climatic Center, Federal Building, Asheville, N. C., 28801).

- Dry Bulb Temperature
- Dew Point Temperature
- Wet Bulb Temperature
- Wind Speed
- Barometric Pressure
- Total Cloud Cover
- Type of Cloud
- Occurrence of Wet Precipitation
- Occurrence of Dry Precipitation

Flat Plate Collector Model -- The flat plate model is based on a tilted flat plate facing south. Although the model allows both the tilt and direction to be specified, they are held constant for any one simulation run. The amount of energy collected is expressed by:

$$Q_{out} = K_1 Q_{inc} - K_2 (T_{in} - D_b)$$

where:

Q_{inc} = Amount of solar radiation incident on the collector surface

T_{in} = Temperature of input fluid

D_b = Dry bulb temperature

K_1, K_2 = Constants for proposed Lennox collector

For 2 cover collector:

$K_1 = .74$

$K_2 = .6$

For 1 cover collector

$K_1 = .8$

$K_2 = .68$

Storage -- Energy storage is accomplished through the sensible rise in temperature of a tank filled with water. For the purposes of our analysis, an insulated cylindrical steel tank with specified length and diameter was assumed. Energy supplied to the tank was assumed to be evenly distributed to all segments.

Two types of insulation for reducing heat loss from the tank were considered - fiberglass and urethane. The thermal conductivity of these materials are:

k (fiberglass) = .26 Btu-in/HR ft^2F

k (urethane) = .13 Btu-in/HR ft^2F

<u>Economic Studies</u> -- A computer subroutine is being used to make economic comparisons between alternate systems and subsystems. The economic evaluations are based on annual cost requirement. The methodology for calculation of the annual cost requirement is based on formulas derived by Grant and Ireson[1] and Rosalie T. Ruegg[2].

Figure 27 is a diagram summarizing the procedure. The output is the annual revenue requirement and is the average dollar amount that would be required each year to cover the cost of operating and paying for the solar system.

The basic inputs needed for the procedure are as follows:

- System cost
- Annual hours of equipment operation (i.e. pumps and fans)
- Energy demand for the building
- Maintenance and major replacement costs
- Energy costs
- Energy escalation rates
- Cost of money

Fuel costs are shown separately because it is expected that electricity will escalate at a different rate than natural gas or oil. Also maintenance costs are separate since the timing of maintenance may not be demanded at a constant rate whereas the operating costs will be constant.

[1] Eugene L. Grant and W. Grant Ireson, Principles of Engineering Economy, Ronald Press Company, New York, 1964.

[2] R. T. Ruegg, "Solar Heating and Cooling in Buildings: Methods of Economic Evaluation", NBSIR 75-712.

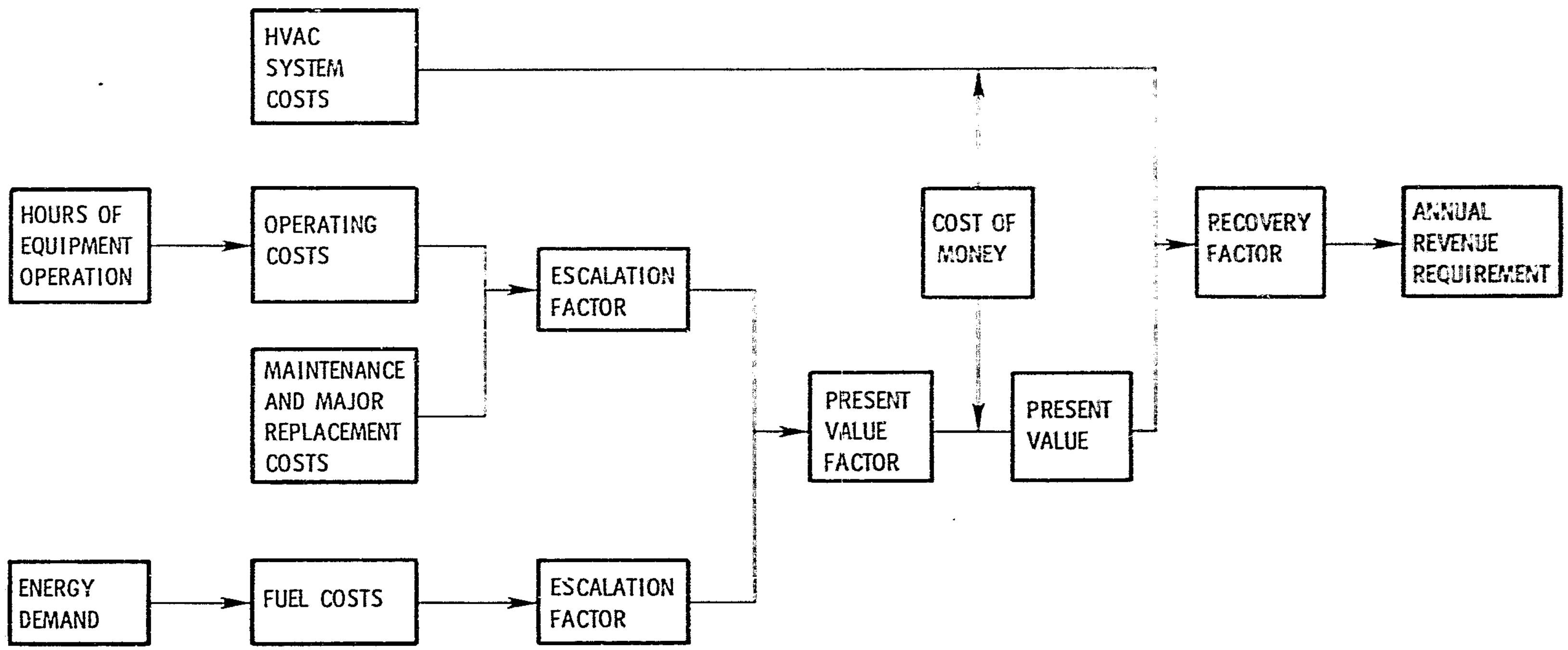


Figure 27. Level Annual Revenue Requirement

The system operating costs, including fuel and equipment operating, are brought to an equivalent basis for comparison purposes by computing the present value. The formula for this is:

$$PV = \frac{1}{(1+i)^n}$$

where i = interest rate or cost of money and n = number of interest periods or years. The interest rate selected for the study was 7%. The economic subroutine in the computer simulation allows for inserting various interest rates for study purposes.

The annual cost required by the homeowner to pay for the system as well as the operating and energy costs is predicted by summing the present value of fuel and operating costs over the life of the system, adding the system first cost and then reducing this amount to a uniform payment by the capital recovery factor formula.

$$CRf = \frac{i\,(1+i)^n}{(1+i)^n - 1}$$

For a 20 year interest period and 7% interest, the capital recovery factor is 0.09439.

The maintenance costs have been neglected. Also not included are allowances for increases in property tax, increases in insurance, or other factors which might increase or decrease payments. Salvage value of equipment at the end of the amortization period was not considered.

Cost of Energy -- The cost of natural gas, oil and electricity for Minneapolis for 1976 were based on current rate schedules recently obtained from Northern States Power Company, Minneapolis Gas Company and Mobile Oil Company. These current rates are as follows:

Natural gas (1000 Btu/ft^3)

ft^3	$
0 - 300	2.4603
300 - 3700	1.9790/1000 ft^3
3700 - 26000	1.5590/1000 ft^3
26000 -	1.5090/1000 ft^3

Oil (14000 Btu/gal)

No. 2	.393/gal.

Electricity

Fixed charge per month -	2.50
First 500 KWH per KWH -	.0353
Next 500 KWH per KWH	.0309
For excess per KWH	.0190

Projected Cost of Energy -- There appears to be many scenarios for the escalation of energy in the future. While future availability problems are speculative, the critical nature of energy use in todays society will obviously result in increased fuel costs. Energy costs, unless regulated nationally, will escalate at different rates for each geographical area.

The escalation rates assumed are the rates presented at the NASA contractors meeting of 3 August 1976. (Reference A. D. Little, "Base Prices and Forecast", April, 1974).

Energy	Year 1976	Year 2000	Rate
Electricity	1	1.4	$(1.014)^{24} = 1.4$
Gas	1	2.72	$(1.043)^{24} = 2.72$
Oil	1	1.68	$(1.022)^{24} = 1.68$

Example of Economic Procedure -- The following example shows the economics procedure for a solar assisted 1500 ft^2 residence in Minneapolis. For present day energy costs (1976) and energy demands based on ASHRAE standard 90-75, the following yearly demands and prices are predicted:

Heating demand	106.6 MBtu
Solar supplied to heating	45.4 MBtu
Electric demand (pumps)	2358 KWH
Hot water demand	3.4 MBtu
Solar supplied to hot water	2.1 MBtu
Fuel cost	$2.5/MBtu
Electric cost	$10.43/MBtu

Assuming electricity escalates at 1.4% per year and natural gas at 4.3% per year, the total energy costs over the next 20 years come to $ 6572.49 which represents a present value of $ 3462.54 at an interest rate of 7%.

In other words, $3462.54 invested at 7% interest would generate enough money over the next 20 years to meet all the energy costs as they occur.

SIMULATION DESCRIPTION

Honeywell has developed a general purpose computer program (SUNSIM) for use in closed loop solar system simulation. This computer program has been adapted for use in the design and evaluation of the solar heating and cooling demonstration systems.

Component relationships and loop constraints are used in the SUNSIM computer program to model multiple loop solar systems as sets of non-linear differential equations. The differential equation may be integrated forward in time to determine fuel savings or linearized numerically for stability analysis using a fully automated modern control software package.

The closed loop simulation structure, illustrated in Figure 28 consists of three key functional blocks:

- o A MAIN program which inputs data, controls the integration and linearization of the differential equations, samples the output and generates report quality output plots and tables.
- o A first order Adams-Bashforth integration STEP routine which updates state variables based on current and past values of the derivatives.
- o A DERIVative routine which contains the differential equations used to model the system.

A derivative subroutine contains deterministic functions of time such as the diffuse and direct components of solar radiation on cloudy days and hourly weather data available for over 300 weather stations in the United States. Two different models may be used to compute the diffuse and direct components of solar radiation.

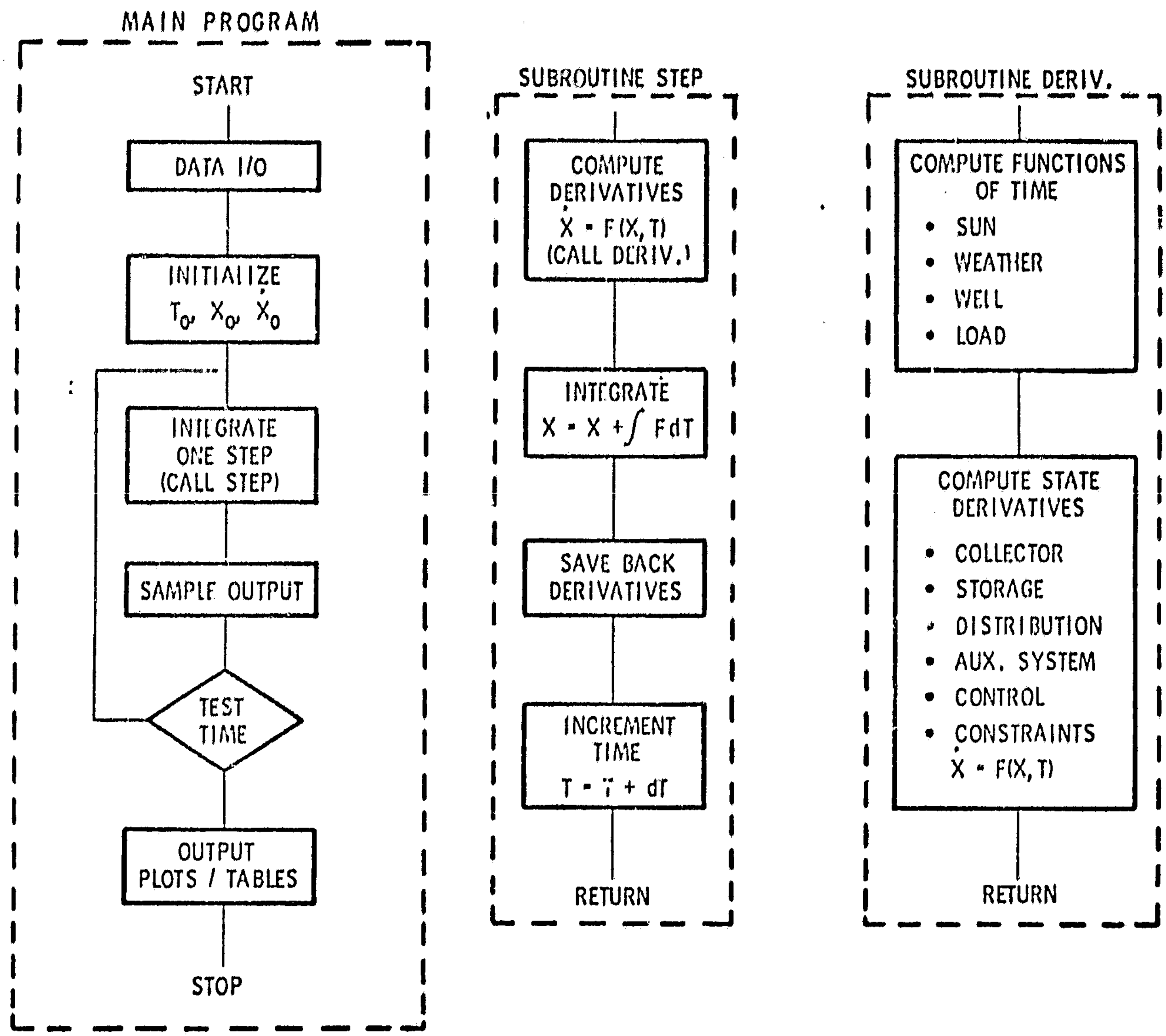


Figure 28. Closed-Loop Solar System Simulation Structure

- An ASHRAE procedure based on weather data provided by the National Climatic Center and a cloud cover radiation model due to Kimura and Stephenson.
- Actual measurements of total radiation on a horizontal surface with an analytical estimate of diffuse and direct components based on a Liu-Jordan correlation. The radiation data is provided on tapes by the University of Wisconsin.

In addition, the DERIVative subroutine contains performance models for solar and conventional system components commonly used in shallow solar ponds, flat plate, Fresnel and trough concentrator systems. The simulation is modular in structure and well documented to minimize modeling time required for the different types of systems.

Figure 29 illustrates four modes of the solar HVAC system being considered for residential space heating and hot water. These are:

- o Mode 1 -- no solar, auxiliary when needed, hot water from storage when available.
- o Mode 2 -- space heating in the direct mode and hot water heating.
- o Mode 3 -- space heating from storage and hot water heating.
- o Mode 4 -- storage charging and heating hot water.

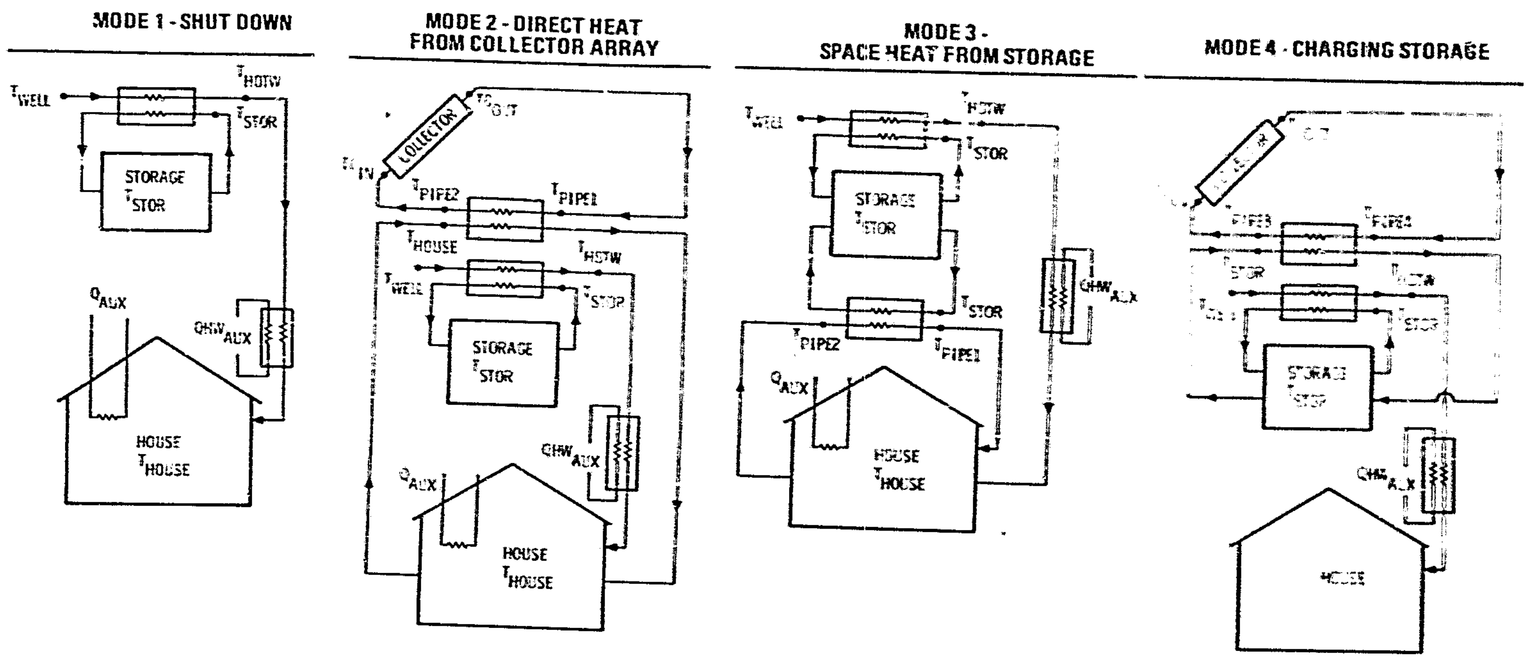


Figure 29. Four Solar HVAC Modes Considered for Residential Space Heating and Hot Water

A first order model of this system has been constructed for use in computing annual fuel savings in support of system design trades. The effect on annual system performance of all major design variables including finite heat exchangers, pumping power, distribution system sizing and insulation, storage tank volume and insulation, loop flow rates and collector manifolding configurations can be readily evaluated with this simulation.

In this simulation, relatively high frequency transients associated with the collector loop thermal capacitance are neglected. As a result, an iterative procedure is required at every integration step to determine the collector loop temperatures in order to satisfy an energy balance constraint on the differential equations.

Simulation of space heating systems and industrial process heat systems have also been conducted using the SUNSIM computer program in which the effects of collector loop thermal capacitance on system dynamics and performance were considered. These simulations required integration steps ranging from 30 seconds to 6 minutes and are primarily used for stability analysis and the investigation of short period effects such as limit cycle frequencies and amplitudes.

RESULTS

Performance and economic simulations of the selected solar assisted heating system was performed for systems for single family residences, multifamily residences and commercial buildings. The trade-off studies began with a "standard" system and various parameters were varied separately to determine their effect on system performance and economics. The effects of these parameter variations have been studied only for Minneapolis and the magnitude of the effects would be different for different localities.

Single Family Residence (SFR)

The basic solar system modelled in the digital simulation program is shown schematically in Drawing SK140094 consists of a collector array with piping headers on both sides of the collectors for inlet and outlet of the collector fluid, a collector with 2 glass covers and a single storage tank filled with water for sensible heat storage. The most important variable which greatly effects both performance and economics is the collector area.

The collector area for the SFR was varied from 180 ft^2 to 756 ft^2. Figure 30 shows the percent of solar energy supplied to a SFR varies from about 21 percent for 180 ft^2 of collector area to about 45 percent for a 756 ft^2 system. These predictions were made for a system with a 1000 gallon storage tank. From this curve, it is not obvious what size system to install since the percent of energy increases as the system collector area increases.

An analysis of the economics of the system by the method described earlier shows that a minimum cost per million Btu's of solar energy provided is realized with a solar system with approximately 540 ft^2 of collector. This is shown in Figure 31. The minimum cost per million Btu's provided is approximately $34/MBtu.

Collector tilt is important. Figure 32 shows that 55° is optimum which corresponds closely to the rule of thumb of latitude plus 10° for heating systems. The performance is within 1 percent of maximum over the range of 45° to 65°. The economics of the system operation for various collector tilt angles is presented in Figure 33. The optimum tilt angle is 55° as was shown in the performance curve (Figure 32).

The performance of the system with the collector array facing away from south was not simulated. It is well known that the optimum system performance is achieved with collectors facing due south. Previous calculations have shown that variations of 30° east or west reduce performance about 3 percent.

The performance of a 540 ft^2 solar system with different size storage tanks is shown in Figure 34. The percent of solar energy supplied to the load varies from about 23.5 percent for a 125 gallon tank to approximately 42 percent for a 1500 gallon tank. The optimum size storage tank is more obvious from curves shown in Figure 35. An analysis of the figure shows that the cost per million Btu's provided decreases rapidly to about 600 gallons and then decreases more gradual up to 1500 gallons. This is approximately 1.11 to 2.5 gallons per square foot of collector. A 1000 gallon storage tank was selected as the preferred size.

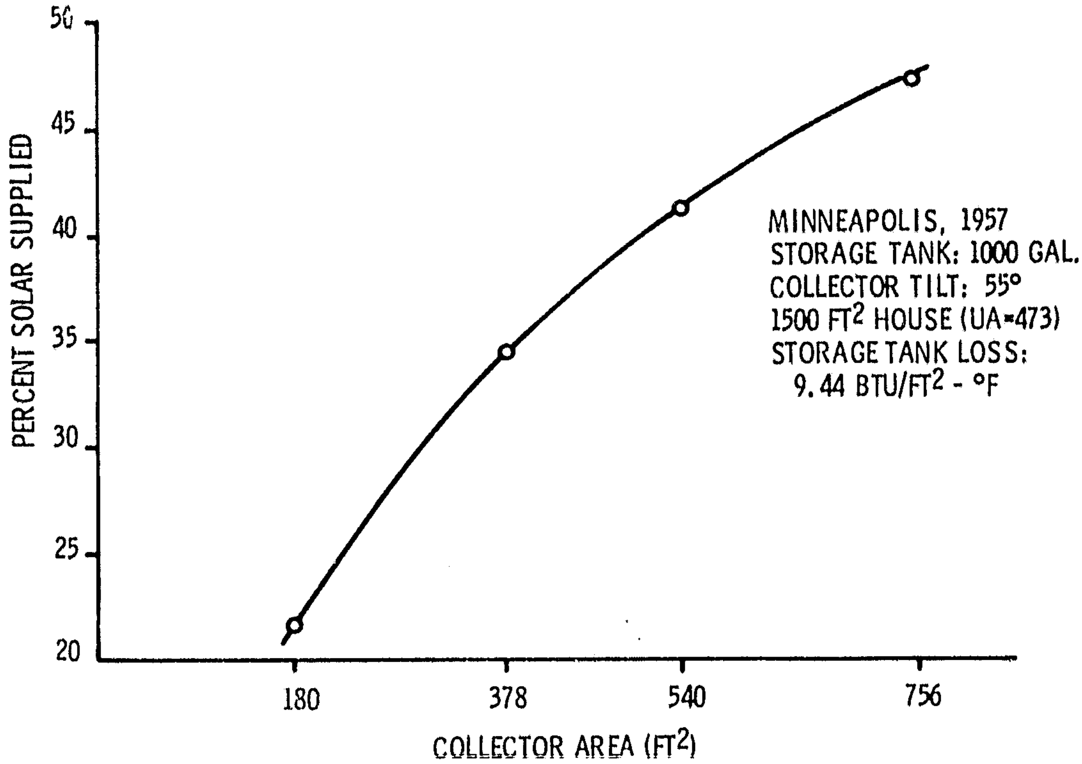


Figure 30. Percent of Energy Supplied by Solar Versus Collector Area

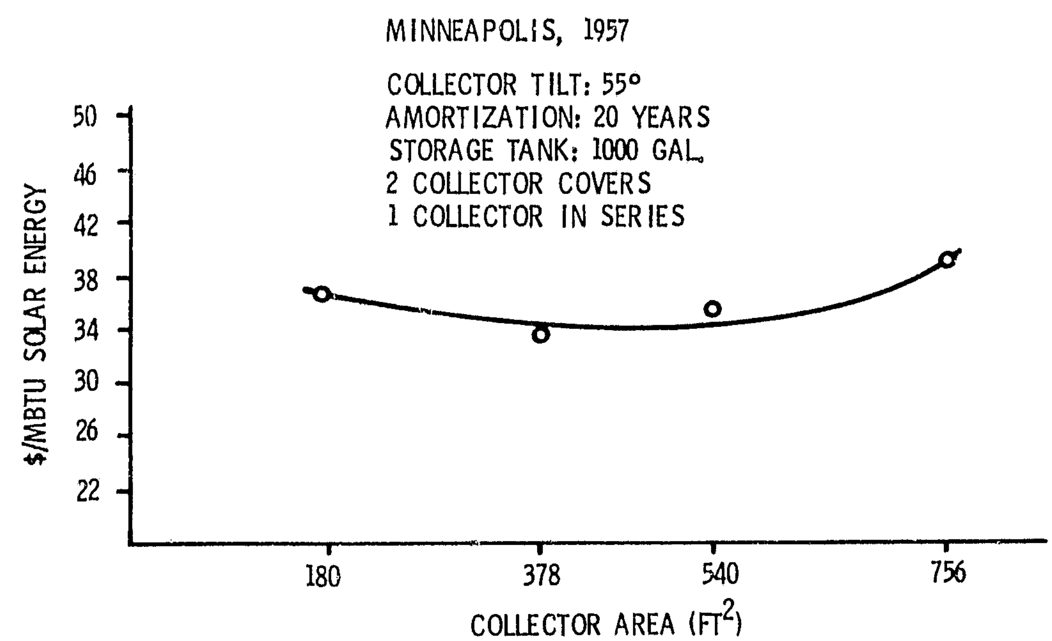


Figure 31. Dollars per Million BTUs of Solar Energy Versus Collector Area - Single Family Residence

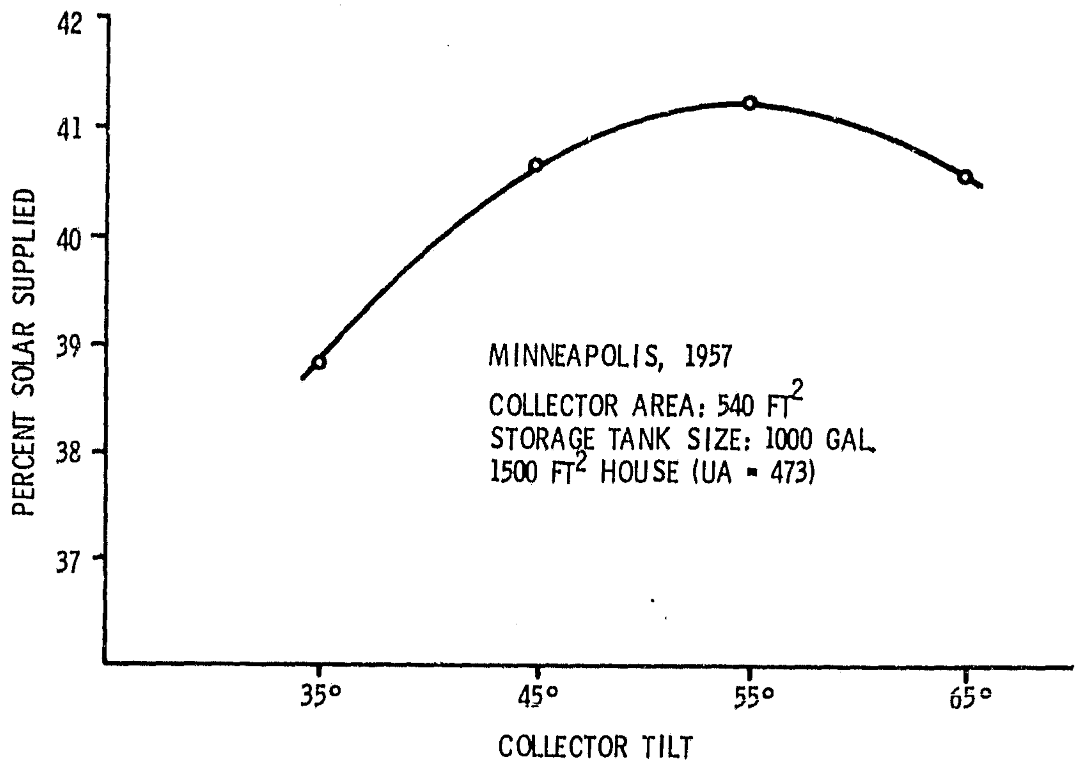


Figure 32. Percent of Energy Supplied by Solar Versus Collector Tilt

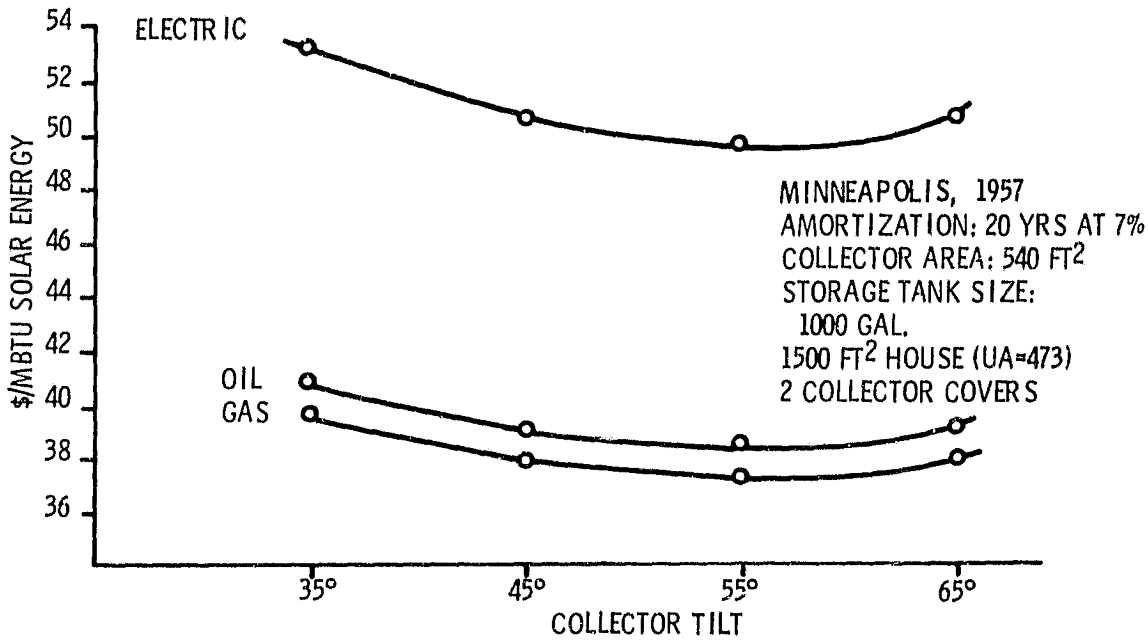


Figure 33. Dollars Per Million BTUs of Solar Energy Versus Collector Tilt

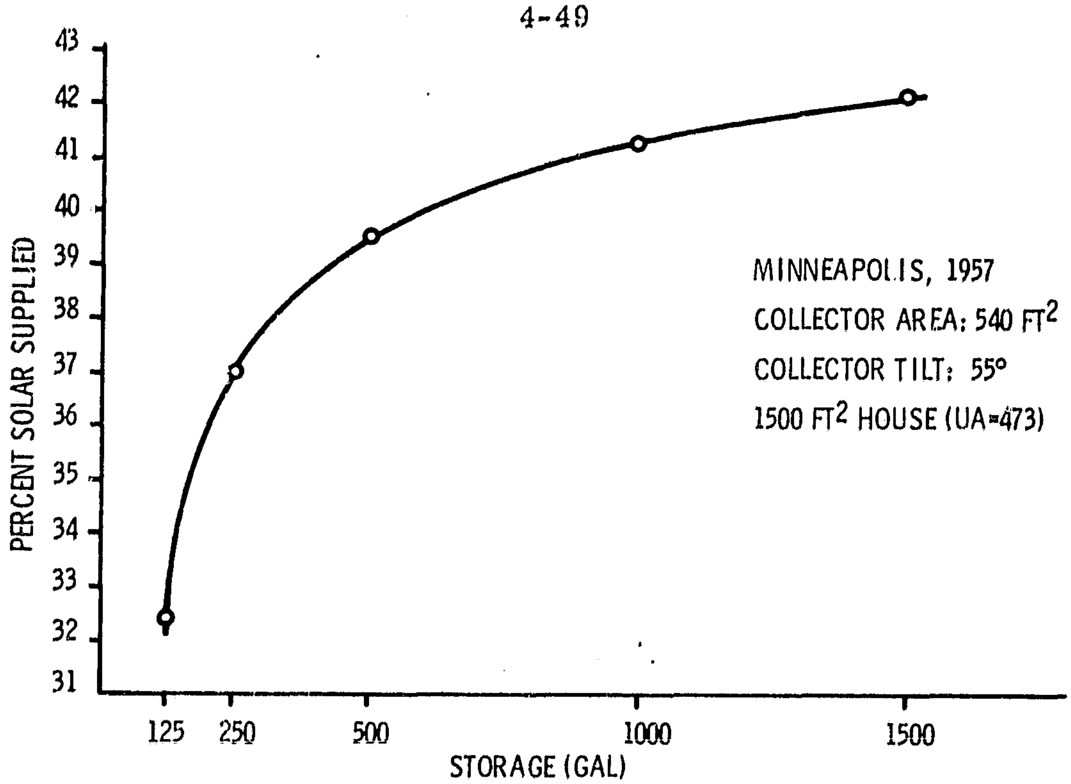


Figure 34. Percent of Energy Supplied by Solar Versus Storage Tank Size

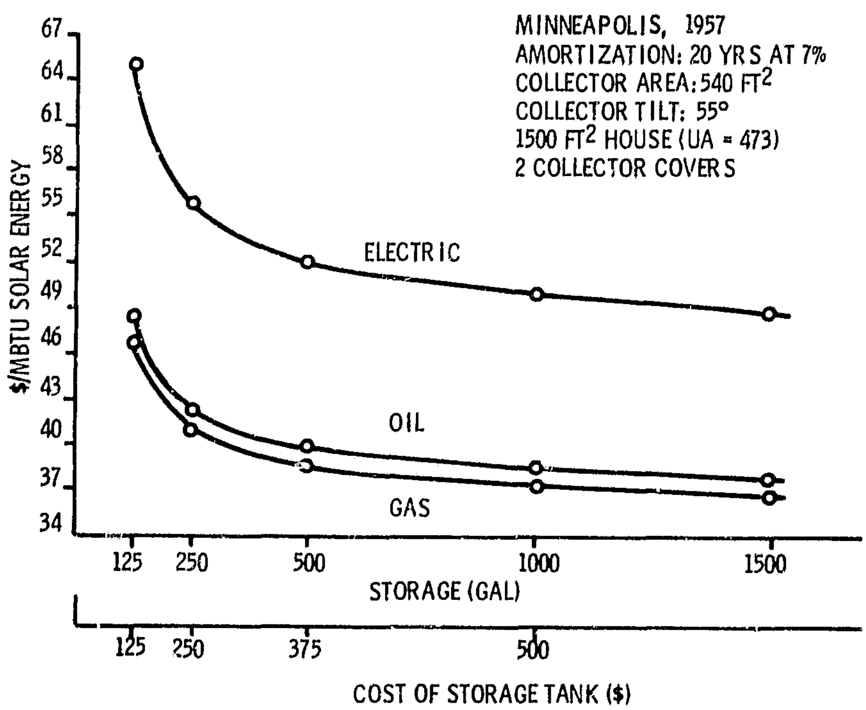


Figure 35. Dollars per Million BTUs of Solar Energy Versus Storage Tank Size

The heat loss from the storage tank was investigated. Figure 36 shows that for a storage tank UA of 9.44 (4 inches of fiberglass), the system would provide about 2 percent less over the year than if no heat was lost from storage. If the storage tank is located inside the building, the heat loss would decrease the building heat load and the net effect would be the same as a perfectly insulated storage tank.

The baseline solar systems described at the beginning of this section have two heat exchangers between the solar collectors and the building air. Figure 37 shows that the performance of the solar system varies approximately 2 percent for a range of heat exchanger heat transfer effectiveness.

A method to cut the cost of solar energy systems is to reduce the piping and solar collector header costs. This can be accomplished by mounting two flat plate collectors in series. The exit flow of one collector enters the second collector directly. Fluid exiting from the second collector then goes into the piping header. The disadvantage of this arrangement is that the performance of the second collector in series is degraded because the fluid inlet temperature is higher. The performance of solar system with the collectors arranged in series is only degraded by a fraction of a percent.

The solar collector can be configured with one cover. This results in the performance equation of the collector having a greater $\alpha\tau$ but also a larger heat loss, U_L. The performance effect of one cover collector versus a two cover collector is presented in Figure 38. The figure shows that the one cover collector provides approximately 2 percent more energy over the year. Figure 39 presents the cost per million Btu's versus the number of collector covers. This figure shows that the overall cost is reduced for the one cover collector.

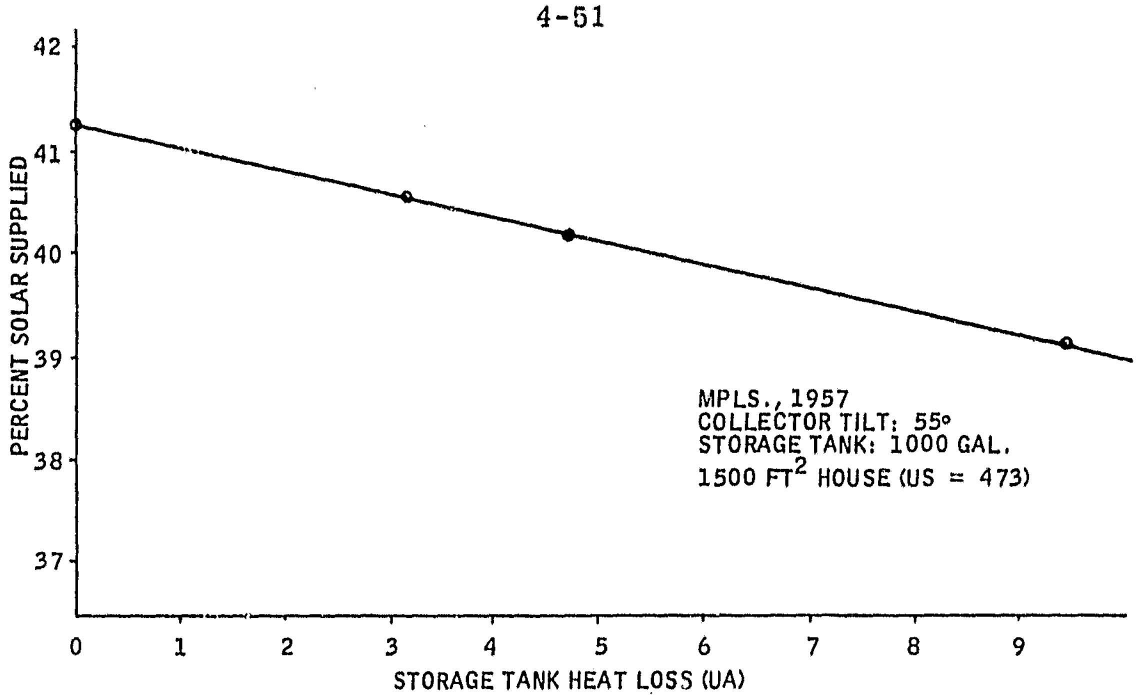


Figure 36. Percent of Energy Supplied by Solar Versus Storage Tank Heat Loss

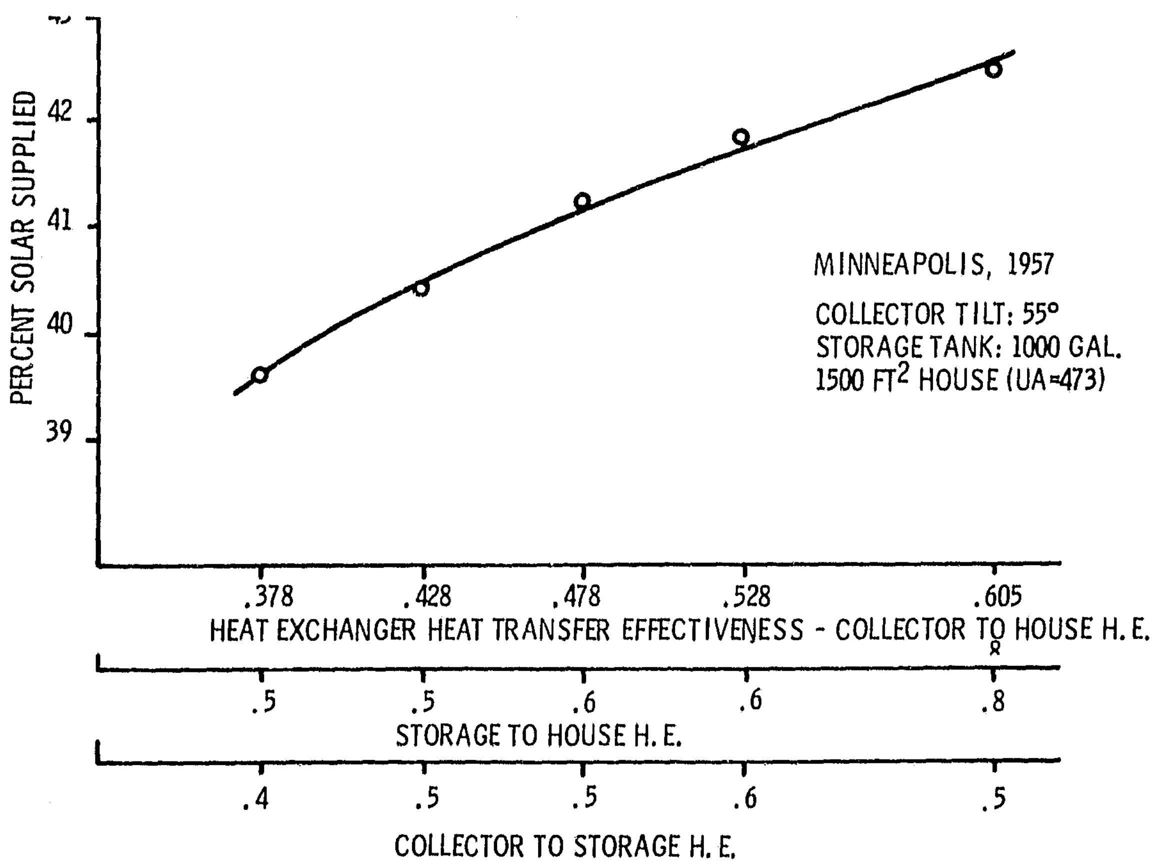


Figure 37. Percent of Energy Supplied by Solar Versus Heat Exchanger Heat Transfer Effectiveness

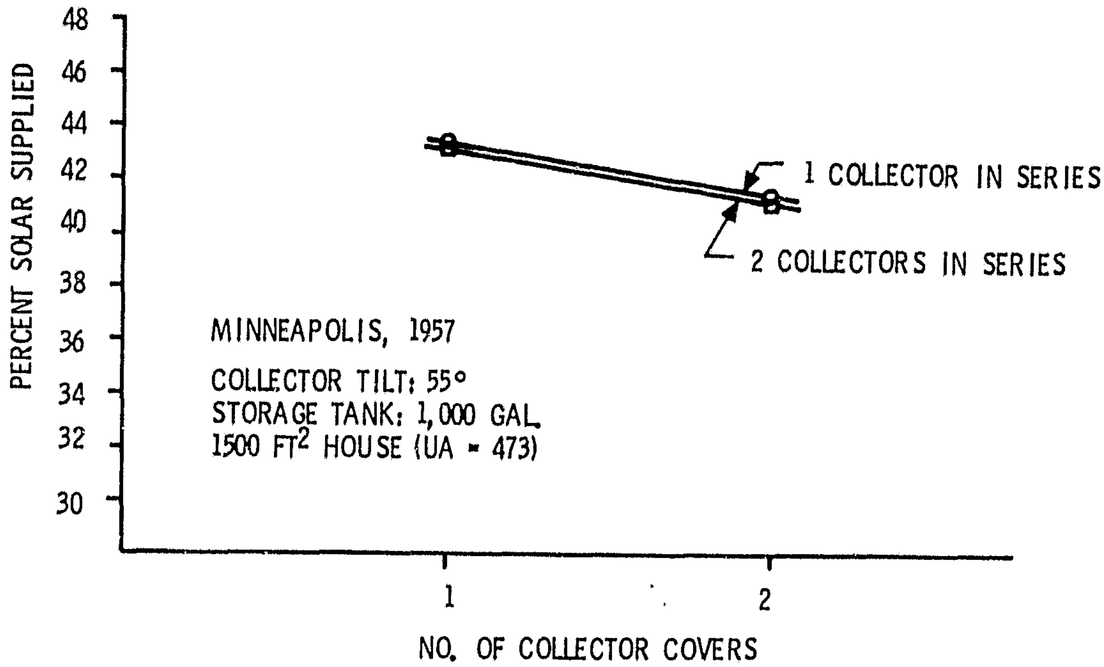


Figure 38. Percent of Energy Supplied by Solar Versus Number of Collector Covers

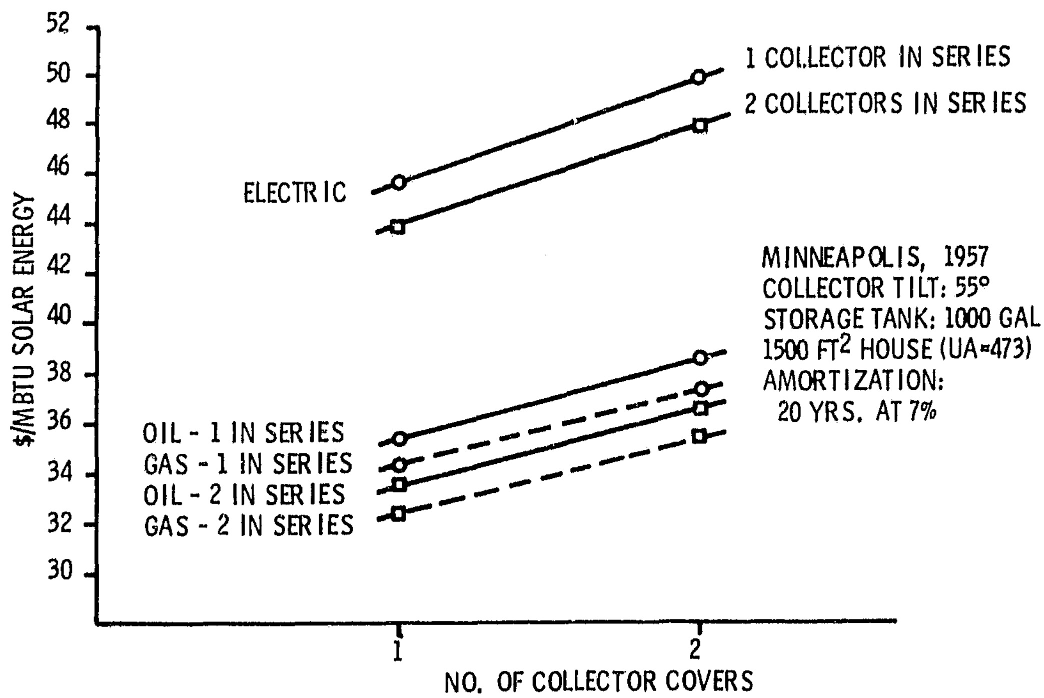


Figure 39. Dollars per Million BTUs of Solar Energy Versus Number of Collector Covers

Multifamily Residence (MFR)

The basic solar system modelled in the digital simulation program is shown schematically in Drawing SK 140095.* The results of the trade-off for the SFR were used so that not all variables needed to be studied. Since collector area is the most important variable, it was optimized. Figure 40 shows the solar cost as a function of collector area. The minimum cost system consists of 3780 square feet of collector or 210 collector modules.

Commercial Building (CB)

The baseline solar system model simulated in the digital computer code is shown in Drawing SK 140096.* As in the multifamily system, the collector area was optimized. The performance of the system was predicted for collector areas of 2484 ft^2 to 11250 ft^2. The percentage of solar energy supplied to the building varies from 36 percent to 74 percent for the cases studied. Figure 41 shows the solar cost as a function of collector area for the commercial building. A minimum cost per million Btu's supplied occurs at a collector area of 5500 ft^2.

* These Drawings SK 140095 and SK 140096 are not included in this report. For information and drawings contact Honeywell-Energy Resources Center, 2600 Ridgway Parkway, Minneapolis, Minnesoto 55413.

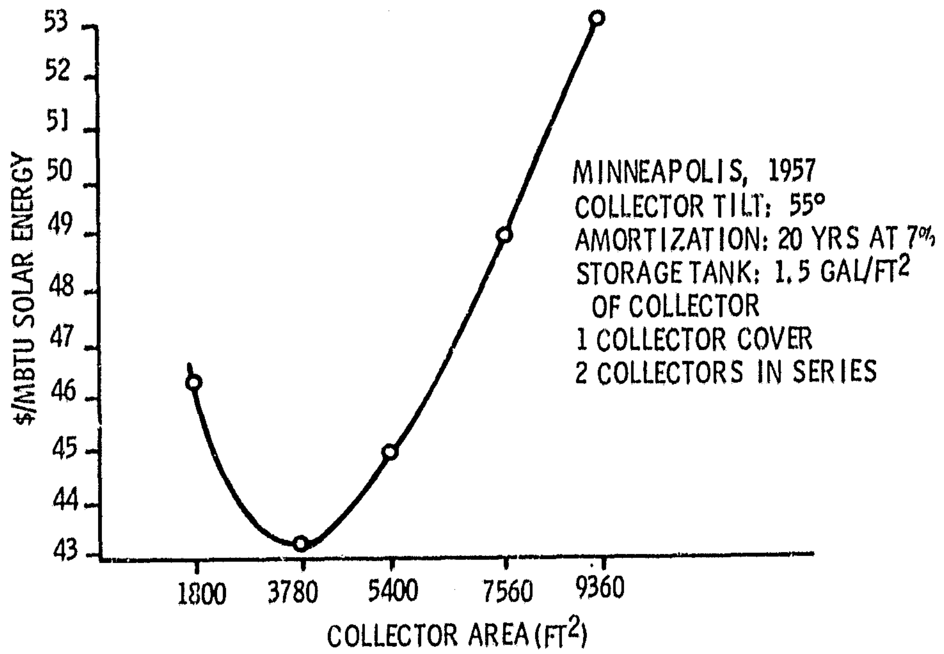


Figure 40. Dollars per Million BTUs of Solar Energy Versus Collector Area - Multifamily Residence

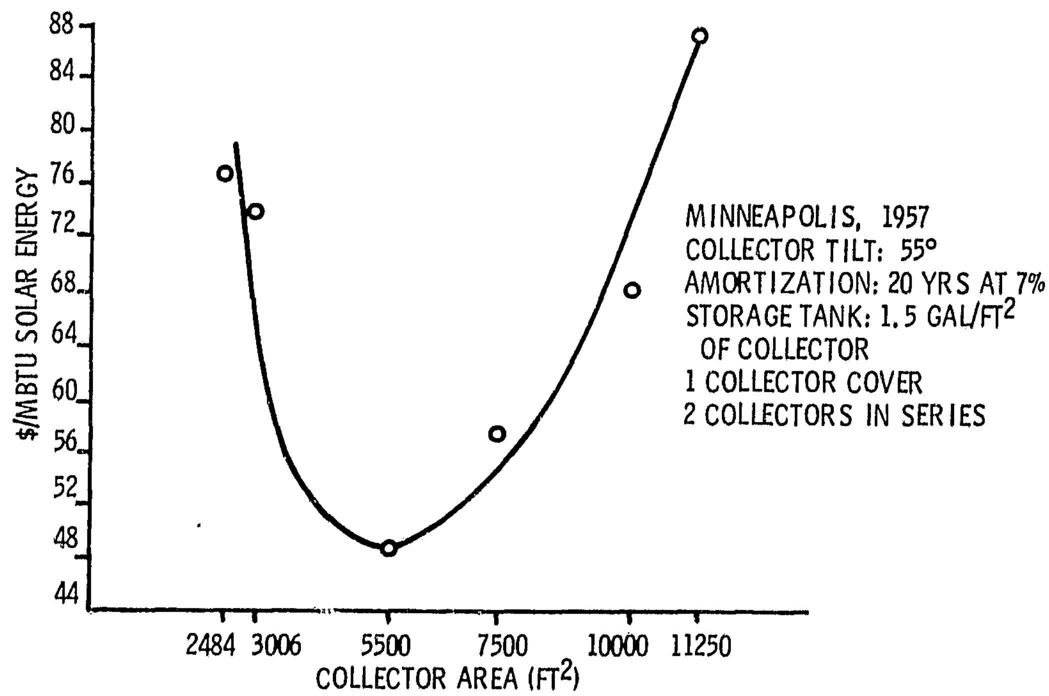


Figure 41. Dollars per Million BTUs of Solar Energy Versus Collector Area - Commercial Building

RECOMMENDED DESIGN

Single Family Residence

The recommended solar assisted heating system for a single family residence is a hydronic-to-warm air system with domestic hot water preheat. The system consists of the following major components:

- 540 square feet flat plate collectors (1 cover)
- Collectors assembled in series-parallel network
- 1000 gallons storage (water)
- Warm air furnace with hot water coil unit

The performance of this system for a Minneapolis 1500 ft^2 house is shown in Figures 42 and 43. The space heating load for a typical year is 106.6×10^6 Btu of which 45.4×10^6 Btu or 42 percent is supplied by solar energy. The yearly service hot water load is 3.4×10^6 Btu of which 2×10^6 Btu or 60 percent is supplied by solar.

The operation of the pumps and furnace fan for the system consume 2358 KWH electricity. The auxiliary fuel cost for a gas furnace is $153.

This system is applicable to new construction as well as retrofit buildings.

As an alternate, an oil furnace could be installed as an auxiliary. The cost of its operation, based on 40¢/gallon oil prices would be approximately $218 per year. If an electric resistance furnace is installed, the auxiliary fuel costs per year would be about $638 based on $.0356/KWH.

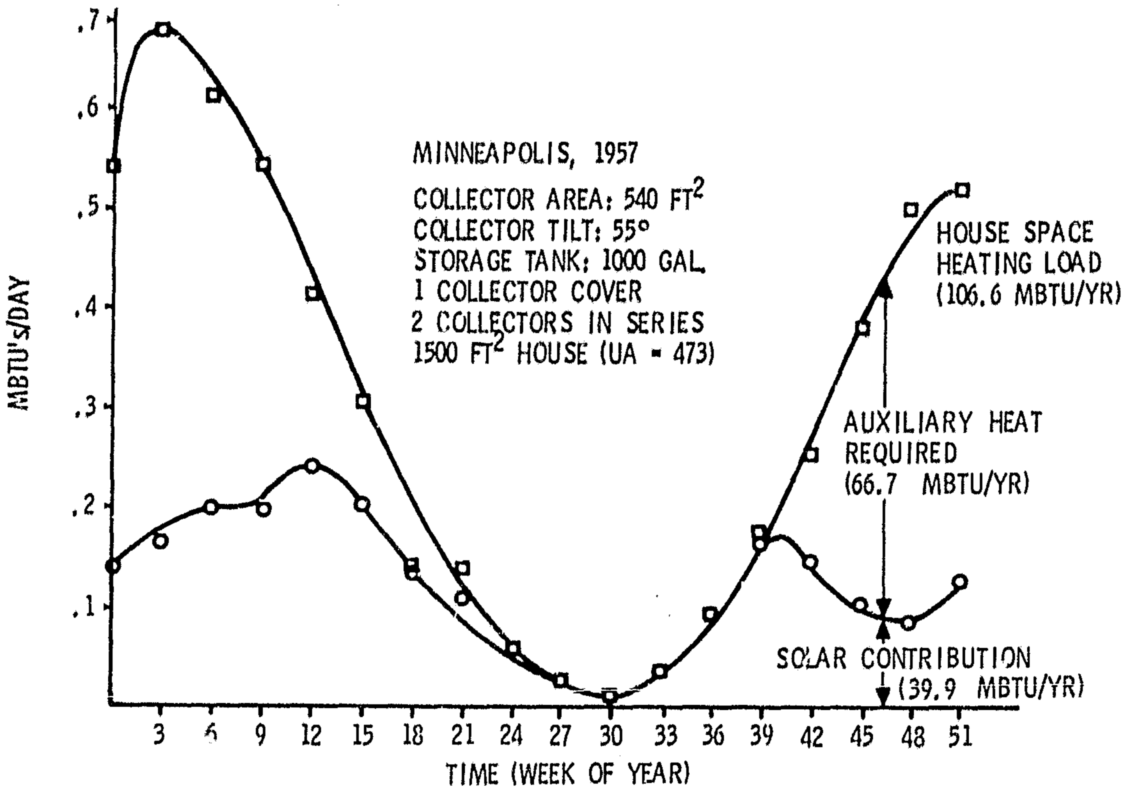


Figure 42. Space Heating for a Single Family Residence

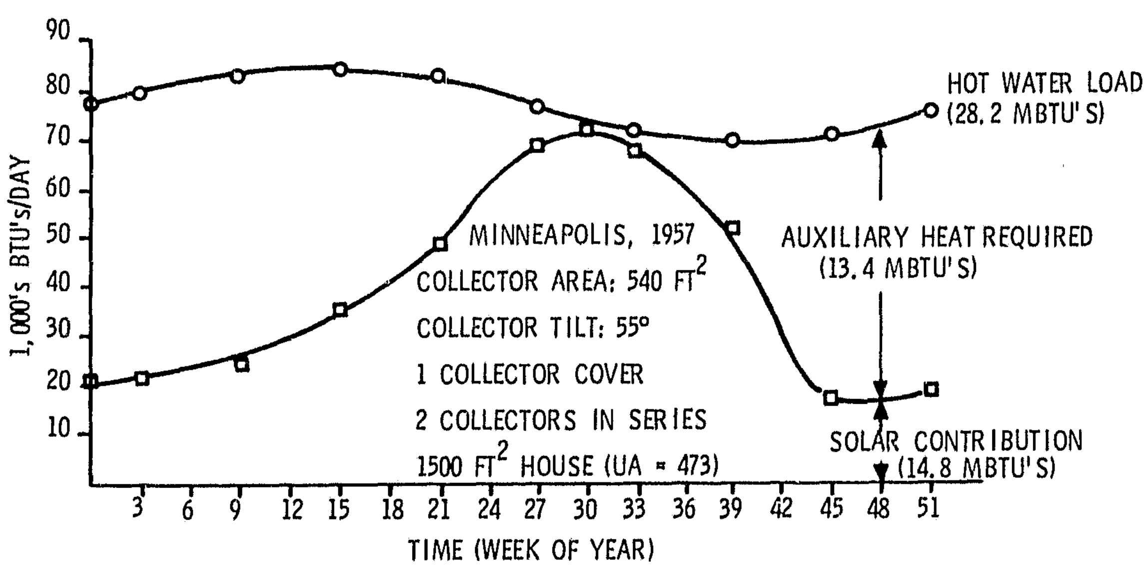


Figure 43. Domestic Hot Water for a Single Family Residence

Multifamily Residence

The recommended solar assisted heating system for a multifamily residence is a hydronic-to-warm air system with domestic hot water preheat. The system consists of the following major components

- o 3780 square feet flat plate collectors (1 cover)
- o Collectors assembled in series parallel network
- o Water storage (1.5 gallons/ft_c^2)
- o Warm air furnace with hot water coil unit

The performance of this system for a Minneapolis multifamily residence is shown in Figures 44 and 45. The space heating load for a typical year is 721.0 x 10^6 Btu of which 339. x 10^6 Btu or 47 percent is supplied by solar energy. The yearly service hot water load is 38. x 10^6 Btu of which 23. x 10^6 Btu or 60 percent is supplied by solar.

The operation of the pumps and furnace fan for the system consume 29362 KWH electricity. The auxiliary fuel cost for a gas furnace is $955 per year.

The system is applicable to new construction as well as retrofit buildings.

As an alternate, an oil furnace could be installed as an auxiliary. The cost of its operation, based on 40¢/gallon oil prices, would be approximately $1364 per year. If an electric resistance furnace is installed, the auxiliary fuel costs per year would be about $3989. based on $.0356/KWH.

A heat pump could also be used to supply the auxiliary energy. Assuming the air-to-air heat pump has a seasonal performance factor of 2.5, the auxiliary energy costs for heating would be $1595 per year.

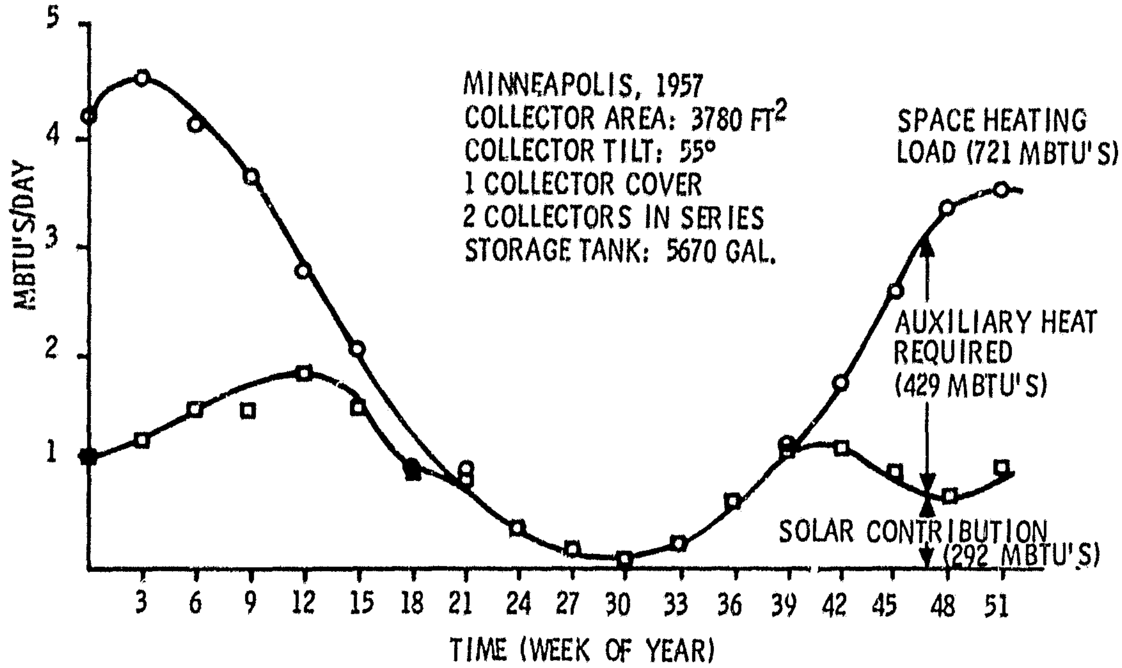


Figure 44. Space Heating for a Multifamily Residence

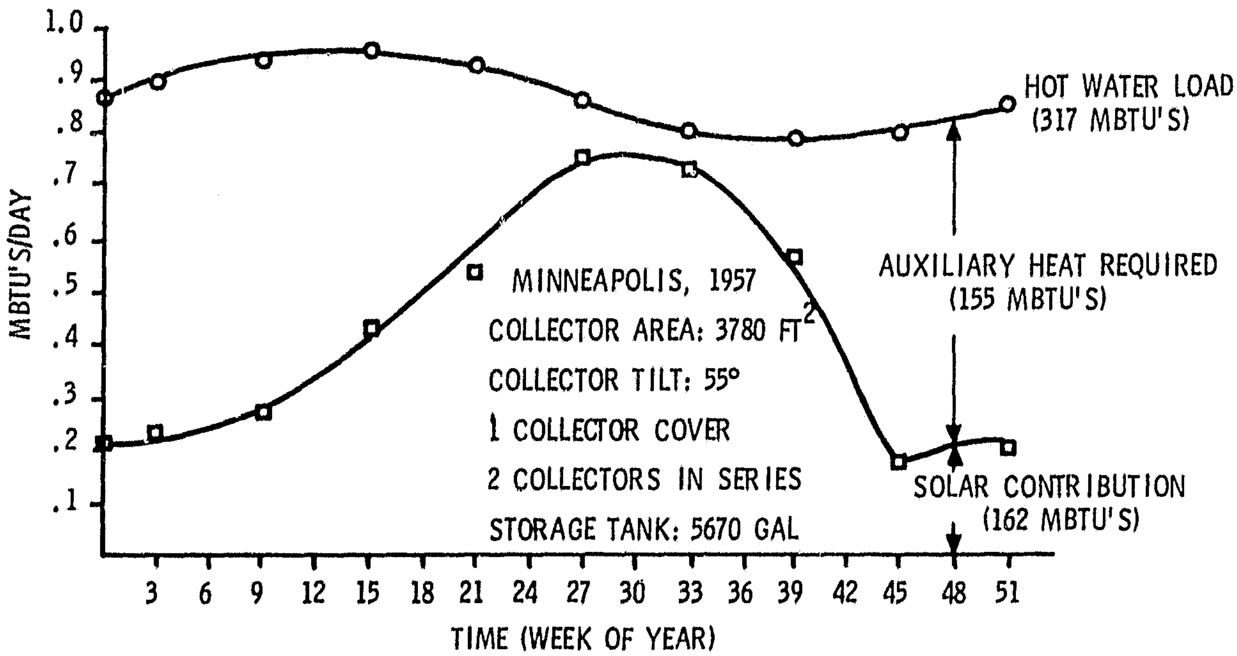


Figure 45. Domestic Hot Water for a Multifamily Residence

A heat pump could also be used to supply the auxiliary energy. Assuming the air-to-air heat pump has a seasonal performance factor of 2.5, the auxiliary energy costs for heating would be $255 per year.

Commercial Building

The recommended solar assisted heating system for a commercial building is a hydronic-to-warm air system with domestic hot water preheat. The system consists of the following major components:

- o 5500 square feet flat plate collectors (1 cover)
- o Collectors assembled in series parallel network
- o Water storage (1.5 gal/ft_c^2)
- o Warm air furnace with hot water coil unit

The performance of this system for a commercial building in Minneapolis is shown in Figures 46 and 47. The space heating load for a typical year is 438.0 x 10^6 Btu of which 352. x 10^6 Btu or 80 percent is supplied by solar energy. The yearly service hot water load is 46.3 x 10^6 Btu of which 41.9 x 10^6 Btu or 90 percent is supplied by solar.

The operation of the pumps and furnace fan for the system consume 22007 KWH electricity. The auxiliary fuel cost for a gas boiler is $215.

This system is applicable to new construction as well as retrofit buildings.

As an alternate, an oil furnace could be installed as an auxiliary. The cost of its operation, based on 40¢/gallon oil prices, would be approximately $307 per year. If an electric resistance furnace is installed, the auxiliary fuel costs per year would be about $899 based on $.0356/KWH.

A heat pump could also be used to supply the auxiliary energy. Assuming the air-to-air heat pump has a seasonal performance factor of 2.5, the auxiliary energy costs for heating would be $360 per year.

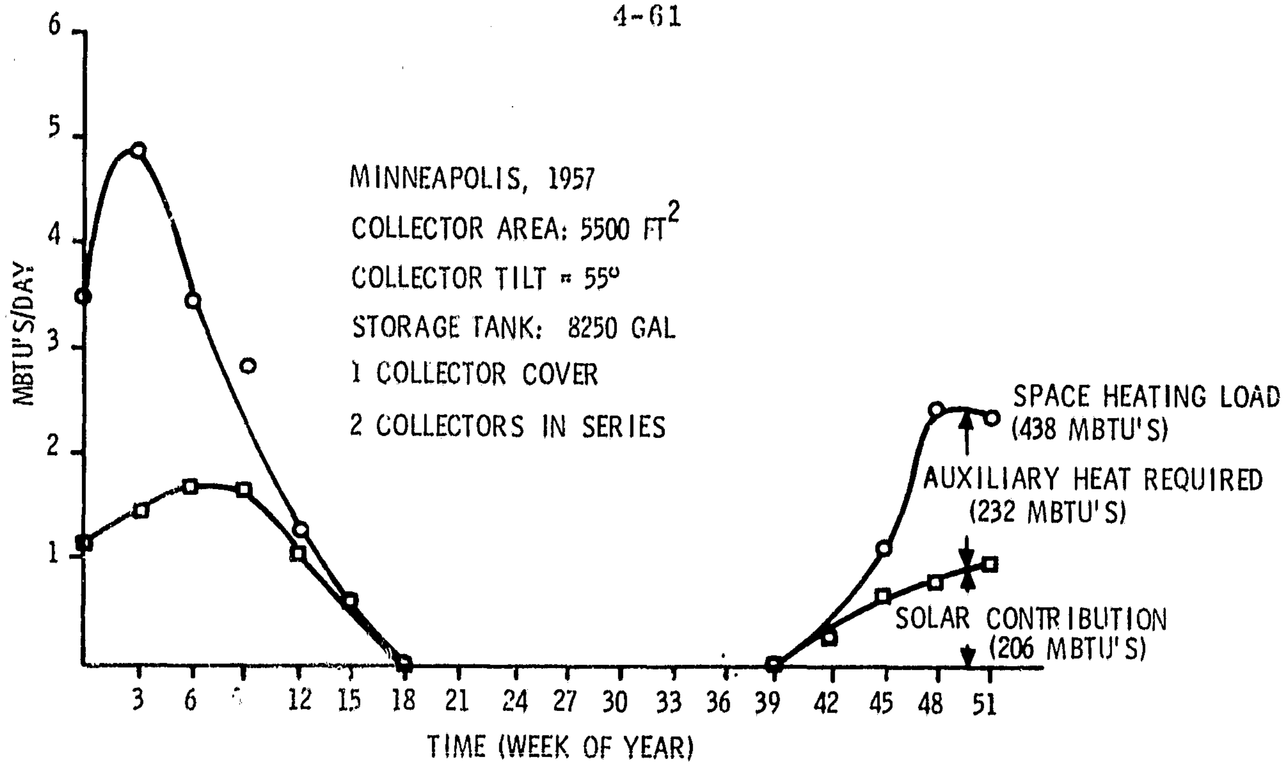


Figure 46. Space Heating for a Commercial Building

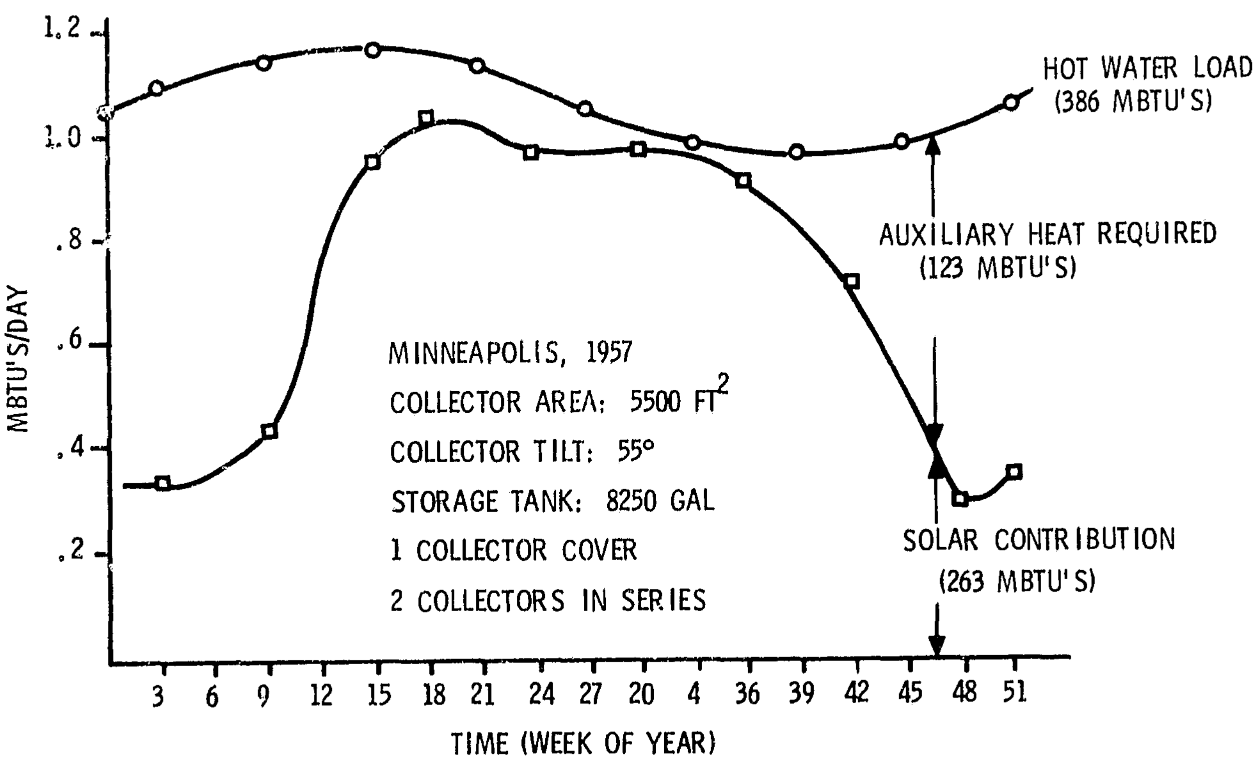


Figure 47. Domestic Hot Water for a Commercial Building

DESIGN AND DEVELOPMENT APPROACHES

Honeywell's approach is to effectively sequence and combine technical efforts to provide the most cost effective prototype system within the schedule guidelines of the statement of work. We have incorporated, as much as possible, subsystems that are "standard" or already have been proven in similar system applications. This will expedite design maturity and keep system development costs low.

With the similarity of subsystems and the varied degrees of performance maturity, Honeywell has laid out a program that maximizes the effective combination of manufacturing development, qualification, and acceptance efforts. This combining and coordination of efforts is reflected in the overall program schedule which includes as parallel effort, the development of residential, multifamily and commercial systems.

The Development Plan (DR 500 Item 1) summarizes the approach, detailed plans for developing the subsystems and a plan for system installation and evaluation.

DETAILED DESIGN PROCEDURE

Following the selection of specific sites, the subsystem designs will be completed for each system. These detailed designs begin with a systematic study of the Interim Performance Criteria and codes and standards for application to the particular subsystem being designed. Next, the particular design tasks which assure compliance with the criteria are completed. Consideration during design is given to modularity, retrofit versus new construction, utilization of off-the-shelf components and designing for a

wide variety of subsystem sizes. Upon completion of the subsystem designs and the subsystem integration tasks, the heating systems will be complete to the extent that the drawings and specifications will form a completed design package.

INTERIM PERFORMANCE CRITERIA AND STANDARDS

The Interim Performance Criteria for solar heating and combined heating/cooling were developed to provide a baseline design criteria for the large number of solar applications being developed at the present time. These criteria will be used to:

- Assure minimum levels of health and safety consistent with similar standards for conventional systems.
- Ensure consistent performance over time.
- Verify that design performance levels will be met.
- Ascertain that systems will be durable, reliable, maintainable and conform to good engineering practice.

The IPC will not be used to take the place of existing standards of good engineering practice or to supplant local or national codes or test and material specifications. The IPC will be used as a framework for applying these codes and standards to solar system design.

Honeywell has used the framework provided by the IPC to consolidate the design standards shown in Table 4 to be used in developing solar systems.

Good engineering practice will be guided by the extensive ASHRAE Handbooks. The Handbook of Fundamentals will be used for guidance in material data, psychrometrics, weather data and methodology of heat load calculations. The Systems Handbook can be utilized for design information

Table 4

APPLICABLE DESIGN STANDARDS AND SYMBOLOGY

Reference	Application
ASHRAE Handbook, Fundamentals, 1972 ASHRAE Handbook, Systems, 1973 ASHRAE Handbook, Applications, 1974	System Performance (H, HC)
ASHRAE Equipment Guide and Data Book, 1972	System Performance (DHW)
National Plumbing Code, ASA, A40.8	Plumbing
HUD Minimum Property Standards 4900.1 Single Family 4910.1 Multi Family 4930.1 Acceptable Practices	Residential System Installation and Structural
ANSI A58.1 1972 Building Code Requirements for Minimum Design Loads in Buildings and other Structures	Commercial Structural
Uniform Building Code, International Conference of Building Officials, 1973	Structural
NBS, Building Science Series 23, 1969	Hail Resistance
NFPA, National Electric Code	Electrical Installation
NFPA No. 89 M NFPA No. 90 B NFPA No. 211 NFPA No. 54 NFPA No. 101 (Fire Standards)	Installation
Public Health Service Drinking Water Standards, HEW, 1962	HW Subsystem

on ducting systems, hydronic system principles, water heaters, heat pumps and systems testing while Applications Handbook can provide solar system guidelines.

The mandatory codes which will be studied and utilized fall into three categories. First the structural codes which dictate structural form and integrity. An example is the HUD Minimum Property Standards which is applicable to Residential and Multifamily installations and deals with structural and asthetic values. It is primarily applicable to roof mounted collectors. The Uniform Building Code is more detailed in mechanical installations and is applicable to both Residential and Commercial structures. The second category of codes covers the installation of mechanical systems. Two examples are the National Electric Code and the National Plumbing Code. The NFPA National Electric Code has gained national acceptance at this time. In 1975, it became an ANSI standard, ANSI C1 - 1975 and it will be used in all installation designs. The National Plumbing Code, on the other hand, has not gained universal acceptance. The closest thing to a national code is the American Standards Association ASA A40.8 Code sponsored by ASME. Accordingly, ASA A40.8 will be used as a guide but local codes peculiar to the site selected will also be checked for compliance.

A third category of codes are the health and safety codes. The National Fire Protection Association has a number of codes influencing the design of hot water heaters, auxiliary heating, high temperature solar equipment, electric motors and controls. In addition, the integrity of potable water will be protected. The guidelines for potable water standards will be taken from HEW Department of Public Health.

As opposed to mandatory controls, there will be the need to draw on standards that affect material selection for the purposes of efficient selection. It is expected that extensive use will be made of material specifications developed by the American Society of Testing of Materials. These same sources will be used whenever appropriate to design tests of materials and components for the sake of standardization. Where appropriate standard tests do not exist, test procedures will be developed.

DESIGN PROCEDURES - COLLECTOR SUBSYSTEM

The collector subsystem is an example of the design procedures to be used on subsystem design and/or development. This product is presently being manufactured by Lennox Industries and is considered developed to the prototype level. However, collector qualification was not complete. A study of applicable IPC was made of those tasks already accomplished to determine what parameters of the solar collector had been sufficiently investigated already. In the case of the collector, the development activity fell into two main areas: function and mechanical configuration.

During collector development, much effort was expended to design a highly efficient collector. Selective coatings and glass transmittance were investigated thoroughly. Therefore, it was determined that the efficiency of collection was a fixed design characteristic at the beginning of qualification and that efficiency of a newly produced collector was not a relevant qualification criteria. At the same time, however, it was apparent that the affect on efficiency of environmental exposure over time had not been sufficiently investigated so efficiency degradation was determined to be a qualification criteria.

The mechanical configuration of the collector was investigated during development yielding a design that permitted easy integration with the structure and a long service life. On element of the mechanical configuration which was not verified during development was exposure to mechanical loads inherent in a structural application.

The result of reviewing the work done during development was a determination that the following tests needed to be conducted to complete qualifications of the collector:

Degradation due to:
- Solar Exposure
- Pollutants
- Thermal Exposure
- Outgassing

Mechanical loads due to:
- Internal Pressure
- Roof Loads
- Hail

After determination of the parameters to be tested, an investigation was made to find or develop suitable test techniques. Wherever feasible, the approach was to make use of existing standard test techniques. Toward this end, the Interim Performance Criteria was used as a baseline to standardize the tests. Referenced test standards were used whenever practical. This approach resulted in a series of tests set out in the following paragraphs.

Efficiency tests which will establish a baseline for determining the extent of any degradation due to environmental exposure were designed around a solar simulator. This was done to permit control and consistency of solar flux which is the most important variable in the test. There is not a standard acceptable test for testing with a solar simulator. The standard test sponsored by the National Bureau of Standards is based on natural sunlight for flux. Because of this, a new procedure was developed using the methodology of the NBS, but substituting the solar simulator for a flux source.

The effects of internal pressure is accomplished by a simple hydrostatic test of the collector pressurized to 150 percent of its rated pressure.

The effect of normal roof loads will be done by determining a uniform load criteria based on standards contained in the HUD Minimum Property Standards. This criteria will be demonstrated by uniformly placing sandbags on the normally supported collector.

The effect of hail on roofing materials is determined by an NBS specification involving propelling a spherical ice ball into the material using a compressed air gun. This procedure will be used without deviation. Collector glass will be considered a roofing material.

The effect of solar flux over an extended time period will be tested in accordance with one of the options in the IPC. Namely, a six month exposure in an area near Phoenix, Arizona where the mean daily solar flux exceeds 500 Langleys. The efficiency of the collector will be measured before and after this exposure to determine if any degradation has occurred.

The effect of airborne pollutants will be determined by exposing coupon specimens of collector parts to ozone, salt, sulfurous acid, hydrocloric acid, and nitric acid. The exposure will be in accordance with IPC standards and any degradation will be determined by using ASTM materials examination techniques.

The effect of the thermal environment will similarly be done using coupon specimens exposed to temperature extremes in environmental chambers. Examination of the coupons will be in accordance with ASTM procedures.

Outgassing of collector insulation will cause a degradation of transmittance of the collector glass. This will be tested by measuring transmittance by ASTM methods both before and after exposure to solar flux.

Upon completion of these qualification tests, the collector should meet all applicable IPC and standards. Details of the application IPC and the qualification tests procedures are contained in the Verification Plan (DR 500 Item 2) and the Qualification Tests for Collector Subsystem (DR 500 Item 13).

In addition, it was recognized that the collectors are modular, suitable for retrofit or new construction and can be combined to provide any subsystem size. It was also recognized that a study of possible flow configurations for various collector arrays should be studied. Of concern is the possibility of non-uniform flow in the collector arrays which can lead to serious degradation of performance. A simulation program was developed from which guidelines will be established for the number and methods of collector arrangements on the supply and return headers in an array. The results of this study will be presented at the Preliminary Design Review.